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Ionospheric Sensor Developments for the Year-2000 Solar Maximum

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13. ABSTRACT *(Maximum 200 words)*
This report summarizes research during the third year of a contract for investigating (a) natural variations in ionospheric total electron content (TEC) and (b) plasma and electromagnetic effects produced by transmitting high-powered HF waves into the ionosphere. The efforts included collecting, processing, and analyzing TEC data from USAF Ionospheric Measuring Systems (IMS) and Real-Time Monitors (RTM) deployed at various sites, maintaining and operating those IMS and RTM units, negotiating the "Year-2000" transition, developing 20-Hz GPS data-collection systems for deployment, and initial developments toward extending current IMS capabilities. In addition to recording TEC variations by means of two-frequency GPS receivers at several locations, work during the year enhanced and exploited several diagnostic instruments deployed for the High-frequency Active Auroral Research Program (HAARP). Under HAARP, measurements employing both GPS and coherent VHF-UHF signals transmitted from satellites in low-earth polar orbit resulted in time histories and latitudinal scans of absolute TEC over Alaska, and enhanced operation of the HAARP classic riometer resulted in essentially continuous observations of 30-MHz radiowave absorption over south-central Alaska. Analysis of a thermal instability expected to enhance generation of ELF/VLF waves by amplitude modulation of an HF heating wave has been extended into the non-linear regime.

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Differential group delay, Dispersive phase, Global Positioning System (GPS), High-frequency Active Auroral Research Program (HAARP), Ionosphere, Space weather, Radiowave absorption, Radiowave scintillation, Riometer, Total electron content (TEC)

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Contents

Preface

This report summarizes work completed during the period from 1 September 1999 through 31 August 2000 on a project to investigate effects of the earth's ionosphere on transionospheric systems.

In addition to the authors, other contributors to the efforts described herein were Northwest Research Associates (NWRA) staff members Charley Andreasen, Angela Andreasen, John Begenisich, Elizabeth Holland, Michael Horgan, James Secan, J. Francis Smith, Tyler Wellman, and David Bruington and NWRA consultants David Barton, William Gordon, Michael Kelley, Spencer Kuo, Sanghum Lee, Jens Ostergaard, John Rasmussen, Allan Schell, and A. Lee Snyder.

We express our appreciation to TSgt. Theodore Denny of the Air Force Research Laboratory at Hanscom for his collaboration in support of the Ionospheric Measuring System (IMS) and the STEL 5010 data recovery; to Randy Hopkins of Raytheon for his on-site support of the IMS at Eareckson Air Force Station, Shemya, Alaska; and to Sgt. Paul Collins for his on-site support of the RTM at Unst, Shetland Islands. We also express our appreciation for the opportunity to collaborate with Captain Kelly Doser of the Air Force Institute of Technology (AFIT) on a study of PRISM and the plasmasphere and to Cesar Valladares of Boston College for collaborative GPS receiver evaluations. We are especially grateful to Peter Ning of Scion Associates for his efforts in reactivating the Ascension Island IMS.

Acronyms and Initials

55 SWXS	55th Space Weather Squadron
AFRL	Air Force Research Laboratory
APTI	Advanced Power Technology, Inc.
ARL	Applied Research Laboratory of the University of Texas at Austin
AWN	Automated Weather Network
CORS	Continuously Operating Reference Station
DICE	Data-driven Ionospheric Correction Experiment
DISS	Digital Ionospheric Sounder System
DVD	Digital Video Disc
IMS	Ionospheric Measuring System
IPP	Ionospheric Penetration Point
IPT	Integrated Product Team
ISR	Incoherent Scatter Radar
ITS	Ionospheric Tomography System
NetCDF	Network Common Data Format
NIMS	Navy Ionospheric Measuring System
NNSS	Navy Navigation Satellite System
NRL	Naval Research Laboratory
ONR	Office of Naval Research
PDR	Powerful Diagnostic Radar
PDOP	Position Dilution of Precision
PRISM	Parameterized Real-time Ionospheric Specification Model
PRN	Pseudo-Random Noise (GPS identification signature)
RINEX	Receiver Independent Exchange (data format)
RTM	Real-Time Monitor
SCORE	Self-Calibration of Range Errors
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SEE	Simulated Electromagnetic Emission
SFG	Scale Factor Generator

sps	samples per second
S-RAMP	Solar-Terrestrial Energy Program Results, Applications, Modeling Phase
SWN	Space Weather Network
TELSI	TEC and Scintillation (message format)
UAF	University of Alaska, Fairbanks
UPS	Uninterruptible Power Supply
UT	Universal Time

IONOSPHERIC SENSOR DEVELOPMENTS FOR THE YEAR-2000 SOLAR MAXIMUM

1. Project Objectives

The ionosphere can both disrupt and enhance the operation of military communication, navigation, and surveillance systems. For instance, the integral of plasma density along ray paths through the ionosphere (the "total electron content," or TEC) imposes range errors on signals received from satellites in the Global Positioning System (GPS). Indeed, GPS transmits two frequencies specifically for the purpose of correcting such error. The correction depends on reliable measurement of frequency-differential "pseudorange." Such corrections can be applied also to nearby or remote single-frequency receivers, a procedure that can be degraded by temporal changes and spatial gradients in TEC.

An objective of this project is to characterize the temporal changes and gradients in TEC as measured by means of GPS pseudorange and more precise measurements of frequency-differential carrier phase as the sun advances in its eleven-year activity cycle. To meet this objective, Northwest Research Associates (NWRA) is (a) operating, calibrating, and maintaining GPS-based equipment, including the Air Force Ionospheric Measuring System (IMS, AN/GMQ-35), at various locations and (b) processing and analyzing data obtained thereby.

It may be possible to enhance operation of some low-data-rate but high-priority communication systems by exercising a degree of control over ionospheric disturbance by means being investigated in the High-frequency Active Auroral Research Program (HAARP). Under HAARP, the Air Force Research Laboratory (AFRL) and the Office of Naval Research (ONR) are developing a facility in Alaska for upper-atmospheric, ionospheric, and solar-terrestrial research. An objective of this project is to contribute to characterizing processes triggered in the upper atmosphere and ionosphere by high-power radio waves to be transmitted from the HAARP facility, specifically as those processes relate to large-scale and km-scale irregularities in ionospheric plasma density and to radiowave absorption. Progress on HAARP topics is reported in Section 2.2.

2. GPS Topics

2.1 Standard Operations

Data files are processed, reviewed, and archived to tape at each of the deployed IMS sites at Ascension Auxiliary Airfield, Ascension Island; Eareckson Air Force Station, Shemya, Alaska; Thule Air Base, Greenland; Croughton Royal Air Force Base, United Kingdom; and Otis Air National Guard Base, Massachusetts. Tapes are catalogued for content and indexed for local storage upon arrival at AFRL each month.

The 15-Minute TEC data from Otis, Croughton, and Shemya are reported by the IMS to AFRL by means of the Space Weather Network (SWN). The data can be plotted for each day to monitor the calibrations, data anomalies, and recent changes in the active GPS constellation.

Such monitoring is conducted at a low level of effort following the decision in September 1998 to deactivate the IMS units at Otis, Croughton, and Thule and the decision in February 2000 to exclude support funding for Ascension Island. A quick bias calibration is performed automatically on the Companion PC at each site, to facilitate detection of bias variations requiring re-calibration. These calculations are subject to some bias errors due to data anomalies, so operator judgment is required in evaluating the results. Because of IMS data utilization by the COBRA DANE radar at Shemya, a regular schedule of calibrations is performed for that site, so that the IMS is re-calibrated no less often than once every two weeks, and sooner if circumstances or data results indicate a need.

GPS ephemeris files are retrieved from Holloman AFB on a weekly basis for use in determining the apparent sky positions of GPS satellites and the associated ionospheric penetration-point coordinates, which are used by the bias-determination process.

A summary log is being maintained for the Otis IMS, the Croughton IMS, the Thule IMS, the Shemya IMS, and the Ascension Island IMS, primarily to monitor the duration of operations for each of the two UNIX computer systems in each IMS. The cause of system shutdown also is recorded in this log. A histogram of system operating-time durations, by month, is included in this summary log for each IMS. A summary table displaying the total percentage of operating time for each month and the number of occurrences of various outage causes also has been included.

2.2 Scale Factor Generator

The TEC and Scale Factor log files from the Scale Factor Generator (SFG) program at Shemya for the period 31 August 1999 to 29 August 2000 were reviewed. Range correction tables are acquired monthly by special arrangements with COBRA DANE personnel or 55 SWXS. These tables are used to determine the appropriate effective sunspot number for the ionosphere model incorporated into the SFG program. An identical version of the SFG program currently is operating on a computer for the operators there, as well as on the IMS-Net PC. Arrangements were made with the radar operators at Shemya to record scale factors determined from radar measurements into the TEC and Scale Factor log files, and these values also are reviewed. The radar scale factor entries ended on 13 May 2000, but were resumed by the COBRA DANE operators on 12 June 2000. The radar scale factors can be compared directly to the SFG scale factors. Daily predictions of the hourly scale factors previously had been retrieved from the 55 SWXS bulletin board, for future inclusion with these comparisons. For technical reasons, these scale factors have been unavailable since 9 November 1998.

For unknown reasons, the range correction table acquired for October 1999 was truncated, so the normal verification and sunspot number determination could not be performed. Consequently, the sunspot number was determined solely from the hourly range scale factors in the table, rather than all of the height, azimuth, and elevation elements of the table. Some techniques developed for this case may be automated to facilitate future use of the range table for sunspot number determinations.

The list of excluded GPS satellites was updated in late August 2000 to reflect additions to the GPS constellation and the inactive status of some satellites.

2.3 Maintenance

In late September 1999, the Otis IMS ceased data transmissions to Hanscom. Investigation indicated that the single UNIX processor operating at Otis was restarting in a mode requiring repairs of the file system, but had inadequate time to complete the process before the IMS heartbeat detection process initiated a system reset. Consequently, local field personnel shut down the IMS unit until a site visit to remedy the situation was scheduled.

In late October 1999, the primary computer for remote monitoring experienced erratic behavior and unusual errors in the use of many application programs, so it was decided to re-install the Windows NT operating system. This appears to have resolved the problems, but some reconfiguration of the system was required to re-establish normal operations. Continuing problems with this computer prompted the assembly and configuration of a new computer system for this role, using components acquired for a rack-mountable Companion PC. The former monitoring system then was configured to replace a printer server that failed.

Also in late October 1999, the local computer used as the primary host for real-time data transmissions and in a secondary role for remote monitoring experienced a number of problems apparently related to the disk system. Several of the disk drives were replaced, and the operating system was reinstalled. On an interim basis, some real-time transmission and archiving operations were established on another computer. The primary host for real-time data transmissions subsequently was reconfigured to restore full utilization of this system in its former capacity. The interim system for real-time transmission and archiving operations then was relegated to a backup role.

In late November 1999, problems with the data-file archiving process were encountered on the IMS-Net PC at Shemya and could not be resolved, even with the assistance of field personnel. After some investigation, it was determined that the tape drive was malfunctioning, so an interim process of compressing the data files for retention on disk was instituted. Because the duration of this option is limited by the available disk space, a supplementary process of transmitting the compressed files to Hanscom was instituted in early December 1999, based on automated procedures previously instituted for the HAARP RTM system. This site was operating without a Companion PC, but the IMS-Net PC has assumed these functions.

New high-capacity hard drives (47 GB) were installed on local computer systems at Hanscom to accommodate interim data storage prior to archiving on CDs, DVDs, or tape. These drives also will be utilized for active data storage for data analysis.

The defective Companion PC for the Thule IMS arrived at Hanscom in late January 2000. As suspected, the problem was associated with the power supply, which was replaced.

One of the Companion PCs in use at Hanscom exhibited unusual behavior in late January 2000 during a software update, and the problem was traced to an incorrect year (2094) reported whenever the system was rebooted. The problem arises at an early stage in the startup process, and can be corrected at the operating system level, but reverts to the incorrect year for the next reboot. The other Companion PCs of the same type were checked and were found to exhibit the same problem. The IMS Net PCs do not exhibit this problem, and one IMS Companion PC with an updated system board does not exhibit this problem. This problem was addressed by the

installation of a supplementary board to assume the clock functions. Three of the Companion PCs were corrected in this manner, but two units still in the field remain to be corrected.

Problems with several tape drives during mid-1999 prompted a survey of tape drive vendors for compatible products, and these devices are being evaluated currently. An alternative mode of archiving using a re-writable DVD also was investigated, but this process was found to be slow and a burden on system resources. A further alternative mode of archiving using a re-writable DVD was investigated and found to be an improvement over the initial software, but further development of this process is required.

A CD containing the updated IMS application software was prepared for use at Ascension Island to allow the installation of the remedy for the GPS Week Rollover by personnel associated with the March 2000 AFRL campaign at that site. Procedure files for the installation process were included on the CD, and separate instructions also were prepared. The installation was successfully completed on 24 March 2000, and network transmissions to AFRL were reestablished on 25 March 2000. Network transmissions to this IMS are blocked by firewall restrictions, and telephone communications are poor, so other monitoring operations and calibration for the Ascension Island IMS are unfeasible.

In preparation for a trip by AFRL personnel to Otis on 28 March 2000, the configuration of the Apollo system that previously had been retrieved from Otis was validated for field use, and this unit was returned to Otis to reactivate the IMS unit there. An IMS-Net PC also was configured for Otis for installation during this trip. Some network incompatibilities for the inter-system connection and the SWN connection were resolved for this IMS-Net PC, and IMS data collection at Otis was resumed. The Companion PC and both Apollo systems initially at Otis were returned to AFRL. The Companion PC was among those treated for the Y2K data initialization problem, and the system disk for the Otis System-B processor was treated for file system repairs, allowing a future return to Otis for field operations.

A maintenance trip to Shemya was conducted in late May 2000, for replacement of a tape drive in the IMS-Net PC and delivery and functional testing of a replacement Companion PC, as well as for general preventive maintenance activities. The interim process of archiving by file compression and network transmission was terminated after tape archiving was reactivated and verified.

The scheduled job for disk file cleanup maintenance on the Companion PC at Otis ceased to operate on a regular basis beginning in late April 2000, but operations were resumed in mid-June after reinstating the scheduled command in a different format. No specific cause for the erratic scheduling has been ascertained.

Several date jumps into the future were encountered for the Otis IMS, beginning in mid-May 2000. Data archiving procedures were remedied manually when necessary, and the problem was finally resolved on 11 July 2000 by completing the installation of the time checkpoint process for the System-A processor. Some further manual file maintenance was required, to overcome improper date tags for files.

On 19 July 2000, a site visit was conducted to Otis to re-install the second Apollo processor and to exchange the Ashtech Z-12 1G02 receiver for an Ashtech Z-12 1A54 receiver, which is

not capable of 20-Hz data reporting. The clock battery for the System-A Apollo processor also was replaced.

The tape drive for the IMS-Net PC at Thule failed on 13 June 2000, so an automated procedure similar to that previously used for Shemya was established to archive the daily data files as compressed files on the disk drive. Some difficulties for the completion of the process and the deletion of subdirectories were overcome. A Companion PC was configured and shipped to Thule in late June to replace the IMS-Net PC, which will be repaired during a field trip in September 2000. Regular operations were instituted on the Companion PC at Thule on 26 July 2000. Further tape drive problems were encountered for this system beginning 21 August 2000, and could not be resolved by on-site personnel, so this system also will be examined during the September 2000 field trip.

The Companion PC at Croughton was experiencing frequent problems with its FTP server application, which is required for data file transfers from the Apollo processors. The file monitoring process was augmented in early July by a procedure to terminate and restart the FTP server if a 30-minute lapse occurred in data file transmissions from the Apollo processors, and several refinements were incorporated into this process. A separate process was implemented for system startup to overcome an improper internal clock setting, resulting from a "Year 2000" BIOS problem. An IMS-Net PC was configured for Croughton and shipped in mid-July, arriving on 27 July for immediate installation by on-site personnel. The Companion PC will be shipped back to Hanscom, for remediation of the "Year 2000" BIOS problem and further investigation of the FTP server problem.

Provisions were implemented on the fielded Companion PCs (or active IMS-Net PCs) to allow separate FTP access from Hanscom, supplementing the file transfer capabilities previously implemented through the remote access features of pcAnywhere.

A preliminary template for troubleshooting documentation was developed, using the 15-Minute report transmissions to Hanscom as a sample case study. Further development of this case study and the template format are continuing.

In August 2000, electrical maintenance at the AFRL facility at Hanscom required the shutdown of all of the local computer systems on two successive weekends. Following the second weekend, several systems could not be restarted due to disk drive problems. Among these was the IMS software Development System. Efforts for obtaining a replacement disk drive for this system are in progress. One of the other computers that failed was completely replaced by a spare computer that had become available.

2.4 Data Network Upgrade

Accommodations for the establishment of a network firewall at Hanscom were performed both prior to and following the event in early September 1999. A number of data transfer protocols were non-operational in the period immediately following the establishment of the firewall, despite prior specifications for their utilization, but many of these were remedied, including the access from within the firewall to the AFRL "DropBox" FTP server outside the firewall. However, the operation of pcAnywhere through the network remains disabled. Alternative dial-up connections are available for the IMS units at Shemya and Ascension Island, but access to the HAARP RTM system is available only through the network. An alternative

network connection was established through a commercial Internet provider to allow access to the HAARP RTM. The standard processing software was installed on the computer for this network.

2.5 Laboratory IMS

Laboratory working models of an IMS, without the enclosure or redundancy of the fielded IMS units, have been constructed at Hanscom for development and testing. Both the Apollo system and the Visualize system were reactivated in late 1999 after dormant periods.

The laboratory working model IMS using the newer Visualize processor was investigated to resolve a sporadic occurrence of an incorrect time zone setting. Previous configuration settings had appeared to resolve this issue, but it recurred in late September 1999 and appeared to affect the database time tags as well as the Telnet sessions. A default initialization assignment was found for one of the user configuration files, and this setting was changed to use the proper GPS time instead of the vendor's default Mountain Time. This adjustment appears to have resolved the problem.

Provisions for using the Uninterruptible Power Supply (UPS) for the laboratory IMS in a "heartbeat monitor" role were investigated. Some capabilities for this mode were discovered for HP-UX version 10, but the implementation appears to conflict with the current interactions between the UPS and the custom IMS Ada software. Other possibilities for using the shutdown processing for HP-UX version 10 appear to exist for implementing this mode. Further investigation of these possibilities will be conducted.

An Ashtech receiver previously shipped for a hardware and firmware upgrade was returned to AFRL in October 1999. This receiver was installed on the Visualize IMS system for testing and evaluation, and functioned normally. The 20-Hz data collection capabilities of this receiver then were verified by a brief test in early December 1999, using the RTM software.

Attenuation tests for an antenna splitter were conducted, using 2-Hz signal strength measurements recorded by the Apollo system. Corresponding high-elevation satellite passes for different days, recorded without and with the antenna splitter inserted, were compared and found to differ by only small amounts, especially when considered relative to the overall signal variation during the pass and multipath effects. The result was encouraging both for further test developments at Hanscom, where conduit limitations restrict the number of GPS antennas that can be utilized on a long-term basis, and for prospective developments for the scintillation enhancement of the IMS units.

In late 1999, data processing capabilities were established on a computer running a preview version of the Windows 2000 operating system, to obtain a preliminary assessment of potential incompatibilities with the new operating system. No incompatibilities were encountered for this preview version of the operating system.

A spare Companion PC was configured to use Windows 2000 as its operating system and installed for use with the Apollo system operating at Hanscom in mid-May 2000. Several refinements of the software configuration have been instituted, including replacement of the FTP server by the current Windows NT version, and further testing and evaluation continue. A

checklist for operational functionality was prepared, and documentation for the system configuration process also was prepared.

Components for a second rack-mountable PC chassis were acquired and assembled, and this system was configured for use at Hanscom as a Companion PC, with the Windows NT 4.0 operating system. To expedite testing, the laboratory Apollo IMS was configured to transmit data files to both the Windows NT rack-mountable PC and the Windows 2000 Companion PC. This configuration operated successfully during August 2000.

Documentation for the different startup script configurations for the Apollo and Visualize IMS computers was prepared, as part of a comparative evaluation of the two configurations and for later reference in evaluating the IMS application startup problems for the Visualize computer. Shutdown script capabilities for the HP-UX version 9 operating system in use on the Apollo computer also were reviewed, to evaluate options for an automated system restart.

2.6 Software Developments

Additional review was performed for effects of the "GPS Week Roll-Over" in August 1999 on the ephemeris and sky position calculations. An initial lack of availability of almanac files from the usual source prompted a survey of other sources, but utilization of these alternative almanacs was hampered by small but significant format and nomenclature differences, which would have required some software changes. Fortunately, availability of the usual almanacs was restored after only a short delay, and these continue to be utilized.

In late 1999, further review of post-processing and analysis programs was performed to address potential "Year 2000" issues. The commercial program used for satellite sky-position plots, time-coverage charts, and coverage histograms was found to be non-compliant for "Year 2000," and a replacement program was sought. Some software candidates were evaluated as trial distributions, but none of these performed with the desired capabilities. Because a program for displaying time-coverage charts from azimuth and elevation tabulations had been developed previously to match existing data-display formats, it was decided to develop additional programs to generate displays for the sky positions and coverage histograms, using the same azimuth and elevation tabulations. A preliminary version of the display for satellite sky positions was developed, with provisions for selecting ranges of time, azimuth, and elevation, and some demonstration displays for Thule were generated. Further provisions for identifying or excluding individual satellites will need to be incorporated into this program, and a program for a coverage histogram remains to be developed.

The existing programs for generation of reference tables of azimuth, elevation, and ionospheric penetration point coordinates were reviewed for "Year 2000" compliance and found to be satisfactory. Two programs that processed RINEX data files were found to require modifications to generate a four-digit year and use a "century logic" algorithm to establish the proper year in the period 1975 to 2074.

An additional development arising from the re-examination of the azimuth and elevation file generation was the identification of parameters controlling the tabulation interval for the generated file. A sample tabulation was generated using a one-minute interval instead of the normal ten-minute interval, producing satellite sky tracks that appear continuous in the graphical

display. The one-minute interval also allows better resolution of satellite rising and setting times and more accuracy for the number of satellites visible above a designated elevation threshold.

Several problems for the "Year 2000" transition were encountered for QBASIC programs used in automated script contexts, in that the reformatting of dates into text strings occurred improperly, because of missing leading zeroes in the generated string. These were remedied soon after the year transition. The Scale Factor Generator program also required a slight modification, to avoid spuriously rejecting data reports by disallowing years with zero decade and units values.

The ephemeris content of the GPS message transmissions was reviewed, for both the RINEX format and the format reported by the IMS, for contingency utilization in circumstances when the almanac files are unavailable and as a basis for other calculations requiring the complete GPS satellite coordinates, rather than only the apparent sky positions. Preliminary calculations were performed using the transmitted ephemeris data, for comparison with current ephemeris calculations, confirming use of the ephemeris variables and validity of the processing. The RINEX format of the GPS ephemeris was adopted for contingency utilization in circumstances when the almanac files are unavailable, as a basis for calculations of the GPS satellite sky positions. A program was developed to use this ephemeris format to generate the current reference table format for azimuth, elevation, and penetration point coordinates, and the results were compared to current ephemeris calculations, with good agreement.

Following the initial conversion of the DOS graphics support software for a Windows NT environment, other graphics application programs have been adapted to utilize capabilities available in the Windows NT environment. Among the benefits of this adaptation are a greater availability of printers (some with color capabilities), higher video-display resolutions and colors, a variety of possible graphical file formats, a more familiar user interface, and the elimination of some performance defects of the DOS version. The following programs have been updated for Windows NT, and other conversions are planned:

- General-purpose tabular listing plotter;
- GPS pass-file plotter;
- IPP database plotter;
- IMS 15-Minute data-report plotter,
- GPS satellite time-coverage.

A new program to plot daily overviews of GPS data, particularly the scintillation index S4, was developed. This program also was augmented to plot the difference between differential group delay and differential carrier phase, as an indicator for multipath and possible bias variations. Optional provisions to display a date and time for the plot creation also were incorporated as a standard feature.

The DOS and Windows NT versions of the plotting program for ionospheric penetration point databases were revised to refine data file handling and reporting features, and to improve data selection capabilities.

The DOS version of the program for plotting satellite coverage periods from the sky position tabulation was modified slightly to resolve a Y2K inconsistency. The program for plotting satellite sky positions from the same tabulation also was enhanced to include an overlay grid for ionospheric penetration point (IPP) latitude and longitude.

The program used for GPS bias calibration was revised to simplify the specifications for Universal Time selection of the calibration time period. The Universal Time range specification is now no longer implicitly dependent upon the site longitude, but remains fixed within the bounds of zero to 24 hours.

An obsolete file termination flag value was removed from pass files generated from RINEX observation files. Most of the post-processing programs could accommodate either the presence or absence of the termination value, but some utility programs produced anomalous results because of the termination flag. Further software development is streamlined by the absence of the obsolete flag.

A diagnostic program was created to tabulate the distribution of time gaps occurring in the standard IPP database files and to evaluate the completeness of the data, based upon the nominal sampling interval and the times of the first and last samples.

Some archaic features were eliminated from the program that concatenates segments of GPS passes, in favor of features supported by Fortran-77 and later compiler versions. Some incompatibilities in handling different categories of pass files also were resolved.

The IMS Ada code was reviewed to address conditions leading to missing summary data for the TELSI messages transmitted to 55 SWXS. No explicit source for the problem was detected in the code, so the next area of investigation is the real-time database. An interim method for addressing the problem is to increase the severity of the error condition from a warning status to a critical status after several consecutive occurrences, forcing a system restart, which operationally has been determined to resolve the condition. A preliminary implementation of this method has been developed and installed at Hanscom for testing.

2.7 Additional Developments

In September 1999, a student from the Air Force Institute of Technology (AFIT) visited AFRL to discuss objectives and methods for a Master's thesis and to gain familiarity with the data analysis procedures and software utilized at AFRL. The subject of study was the effect on PRISM of input data containing TEC contributions from the plasmasphere, which follows an earlier AFIT study attempting to quantify the TEC content of the plasmasphere and uses some of the same data. This study also utilizes some procedures developed earlier in 1999 by AFRL, Computational Physics, Inc., and NWRA, for preparing calibrated TEC data for use by PRISM. Preliminary versions of this thesis were reviewed, especially those sections discussing the utilization of SCORE and interpretations of the ionospheric data. This research project concluded with a Masters thesis presentation by the AFIT researcher in late January 2000.

Preparations were conducted for an IMS Program Management Review (PMR), held at 55 SWXS in early November 1999. In addition to developing plans and budgets for standard operations and maintenance activities for the current federal fiscal year, plans and budgets also were developed for communications and scintillation upgrades for the IMS units. Aspects of these upgrades were intended to fulfill some of the original operational requirements for the IMS, so documentation relating to these requirements was reviewed prior to developing the two-year plan for these efforts. Further refinement of the maintenance budget was conducted after the PMR, to match performance categories to the particular funding channels utilized by 55 SWXS.

In preparation for the "Year 2000" transition, all network operations at AFRL/Hanscom were terminated at the end of the business day on 30 December 1999, and all computers were shut down. Resumption of network operations commenced on 3 January 2000, and monitoring operations resumed on 4 January 2000. Manual file transfers were initiated from remote sites to recover from the interruption in operations.

Preliminary discussions were conducted to plan support for the Data-driven Ionospheric Correction Experiment (DICE), including the format of the validation data and calibration procedures for TEC measurements. A demonstration of the current calibration process was provided to AFRL personnel.

Spreadsheet techniques for tabulating summary diurnal TEC profiles were adopted to generate a table of peak equivalent vertical-TEC values for the Shemya IMS for the previous year, to synopsize effects of the approach to Solar Maximum, expected this year. The TEC data were tabulated only for calibrated data sets, to achieve the greatest accuracy. Seasonal and short-term variations predominate, but a slight trend of increasing TEC is apparent. (See Figure 1.)

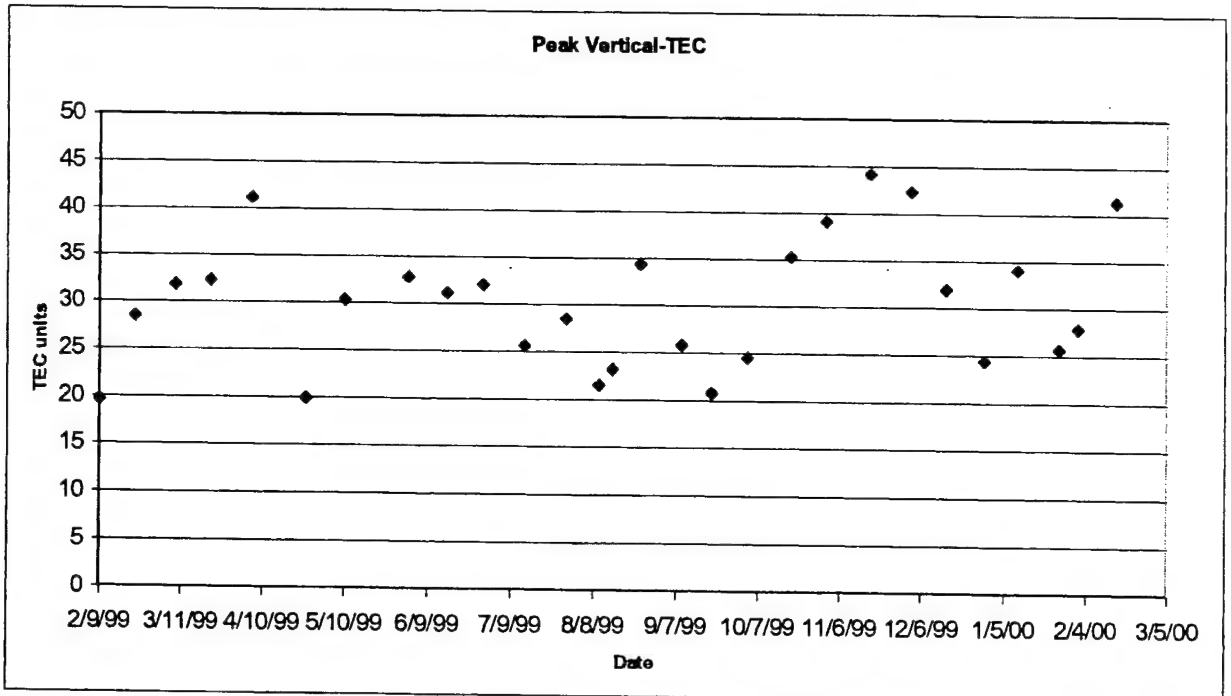


Figure 1. Peak daily vertical TEC for calibration days at the Shemya IMS.

A data tape containing files archived during the March 2000 Ascension Island campaign was brought to AFRL, and the files were restored to local storage disks. The TEC data were processed to determine bias values and plasmasphere amplitudes, and plots of the daily TEC pattern were generated. Particular time intervals were selected for more detailed evaluation of the 2-Hz signal intensities and phase, currently in progress.

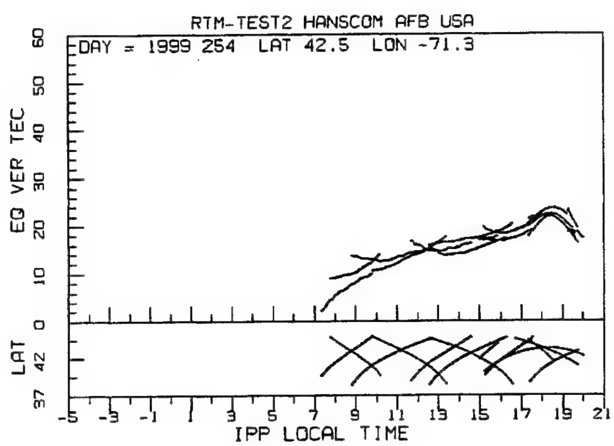
Several changes and interim configurations of the GPS constellation have affected several operational functions, including the selection of days for calibrations and the specification of

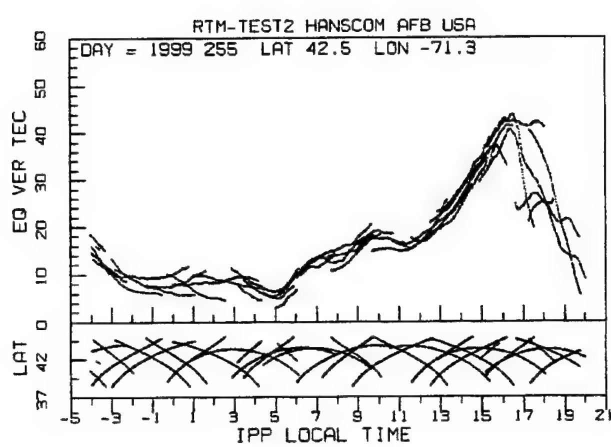
valid satellites for the Scale Factor Generator. Information about the constellation changes is being monitored, and such changes are incorporated into an on-site log for further reference.

2.8 Alternative Data Evaluations

RTM systems are being operated at Hanscom for development of data collection and processing methods, with particular application to the data-collection systems deployed at the Shetland Islands and HAARP. Various software and script revisions and additions are tested on these systems before use on the deployed field systems.

One of these RTM systems was operating on 12 September 1999, which was a night that AFRL personnel reported aurora in upstate New York. The equivalent vertical-TEC profile for that date showed a significant enhancement over neighboring days, with some indications of a mid-morning depletion. The three-day sequence of TEC profiles is displayed in Figure 2.





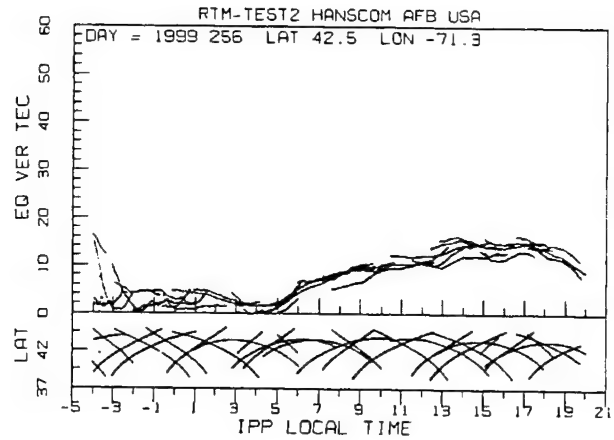


Figure 2. Three successive days of vertical-TEC profiles at Hanscom, showing significant TEC enhancement on day 255 concurrent with an auroral event in the northeastern United States.

In late August 1999, a Boston College researcher at AFRL acquired a Leica GPS receiver for ionospheric studies, and a joint evaluation with NWRA personnel was conducted at Hanscom. Data collection on one of the RTM systems was suspended, and the Leica data collection software was installed on this system. Some difficulties were encountered for the initial Leica receiver operations, and, after checking the specification documents for compatibility, the Leica antenna was operated with one of the Ashtech receivers. Some GPS satellites were tracked in this hybrid configuration, although there appeared to be a higher elevation threshold for satellite acquisitions, possibly due to lower gain in the antenna preamplifier. The other antennas available at Hanscom were not compatible with the Leica receiver, so other alternative configurations could not be investigated, and combined operations of the Leica antenna and receiver still produced no successful signal acquisition indicators from the receiver and no GPS data, even with a change in the total length of the antenna cable to minimal requirements. A replacement receiver was acquired, which immediately showed indications of GPS signal acquisition after its installation, and further data indicators were obtained using the data-collection software, so the first receiver was considered defective.

Data collection from the second Leica receiver was initiated and allowed to continue for several days. A preliminary review of selected individual satellite passes showed good agreement with other GPS receiver data collected at Hanscom for the same period. A full calendar day of data was acquired in RINEX format and processed using the current post-processing and calibration procedures, to obtain a calibrated vertical-TEC profile that matched other data collected at Hanscom. A Leica representative visited Hanscom during this operating period to demonstrate various data-collection options for the software and to discuss the suitability of the higher-rate (10-Hz) data for scintillation measurements. This second receiver and the original antenna then were taken to South America for independent studies.

In September 1999, AFRL purchased a Leica receiver and antenna, and these were delivered to Hanscom in November 1999. An initial test indicated that this receiver system was functional, and further testing was conducted. This receiver was configured for 10-Hz data collection of

group delay and phase for both GPS frequencies, and one hour of data was collected at Hanscom. The RINEX file generated from this data collection was processed using existing software, and detailed analysis was performed of the two phase records collected from each of four satellites. After linear detrending, a sawtooth pattern is evident in the phase data, corroborating reports by a Boston College researcher of the same effect in a different Leica receiver. Further analysis of successive differences between phase samples indicated that the phase increments (or phase rates) are quantized, with different quantization units for the two GPS frequencies. The quantization is not apparent in the dispersive phase, which had previously been demonstrated to produce valid TEC measurements, but the precision of this dispersive phase remains to be investigated.

This Leica receiver is being evaluated for future fieldwork for TEC measurements or position determinations. Procedures for initiating automated data collection and partitioning data collection files are being developed.

2.9 International Collaborations

An RTM data-collection system continued operations at Unst, in the Shetland Islands, with regular dial-up connections from AFRL. The tape drive was found to be inoperative after data collection was resumed with a replacement antenna in April 1999. An alternative process of disk archiving was established, using the large spare hard drive installed in the computer. Even with file compression, disk space was being used at a rate of about 10 MB per day, and the available space was expected to be exhausted before the end of December 1999, although revised estimates in mid-December indicated about another month of available space for data collection. A replacement computer was configured for shipment to Unst, but before this shipment could be accomplished, the tape drive for the computer at Unst resumed operation on 12 January 2000, when a replacement modem was installed in the computer. Normal operations have continued, while files previously archived to the hard drive were transferred to tape. This tape and subsequent tapes have been received at Hanscom for cataloguing. Archived data are being processed for calibrated TEC diurnal variations.

2.10 Qaanaaq Campaign

Another RTM system was developed for deployment to Qaanaaq, Greenland, just north of Thule Air Base, for the SCOSTEP/S-RAMP International Space Weather campaign occurring in mid-September 1999. This system utilized the 20-Hz Ashtech data collection in addition to the standard TEC data collection, and was configured for autonomous operations, for possible continued deployment after the campaign. Unfortunately, the data-archiving tape drive failed to function immediately on deployment, so the system was returned to AFRL at the conclusion of the campaign. The tape drive exhibited erratic performance and required further evaluation, but it was possible to recover all of the RTM data for the campaign from the disk drive, storing them on a local disk. Other files developed especially for this campaign also were retrieved from the disk drive of the RTM computer, while the system appeared to experience degraded operating performance. The entire computer system was examined and may require significant refurbishing or be discarded.

A preliminary survey of the 20-Hz Ashtech data was conducted, using software provided by the Applied Research Laboratory (ARL) of the University of Texas at Austin. This survey was

restricted to data integrity issues, especially partial data records and data gaps. An unusual two-minute pattern of data errors was seen over some periods, but no direct cause could be ascertained, either in the data-collection process or in possible resource-contention activities in the computer system.

A preliminary survey of scintillation occurrences was conducted using one-minute S_4 measurements, recorded in a RINEX format by the RTM program. The scope of this effort was greatly reduced by information from the campaign participants that significant scintillation occurred only on the last two days of the campaign (days 264 and 265) and by preliminary survey data from the Novatel receiver indicating specific satellites and times of scintillation events. An additional scintillation event was determined from the Ashtech survey and confirmed in the Novatel data. Lower levels and occurrences of scintillation than expected were encountered for this campaign, and the scintillation intensity fluctuations did not exceed the threshold imposed by multipath from low elevations and near-field objects. One-hour files of the 20-Hz data containing these scintillation events were provided to ARL for further examination.

With the commencement of the campaign, plans were devised for scintillation software development and data processing procedures, including definition of a new data format appropriate to the large quantity of 20-Hz data. Sufficient flexibility was sought for the data format to allow its utilization for other high-rate TEC data, particularly the STEL 5010 20-Hz data, which currently are being archived at AFRL. A description of the format is presented in Table 1. The data-storage format used by ARL for the 20-Hz data, together with the source code of their data-translation program, were reviewed as part of this planning. Development of the preliminary software for data conversion was completed by mid-November 1999, but testing, evaluation, and some software enhancements were delayed by other activities. A preliminary display program for the new scintillation data format was supplemented by a version for Windows NT, and provisions to plot individual items, instead of a fixed set (consisting of signal intensities and differential carrier phase), also were incorporated.

Concurrent with the scintillation software development, preliminary data processing was performed, using the programs and data formats available at that time, and developing some new procedures as needed. TEC data were processed from the RINEX file of one-minute averages, and one day of these data was calibrated, for application to the entire campaign. Furthermore, the 20-Hz data for the last two days of the campaign were translated into text tabulations using a program provided by ARL. These tabulations (one for each hour) were partitioned into separate files for each GPS satellite and each hour, allowing preliminary detailed plots to be generated by existing display programs. Detailed plots of 20-Hz scintillation intensity data for the scintillation events were generated together with matching plots for (uncalibrated) slant TEC data from differential phase, but no consistent correspondence pattern was apparent. The files for individual satellites later were used as part of the validation process for the scintillation software development.

Table 1. Contents of Individual Binary Pass Files for Scintillation Data.

Header (Once per File)
(Integer; 1 Byte) GPS Satellite PRN Number
(Integer; 2 Bytes) Day-of-year
(Integer; 2 Bytes) Four-digit Year
(Real; 4 Bytes) Site Latitude (Degrees, Positive North)
(Real; 4 Bytes) Site Longitude (Degrees, Positive East)
Data Records (Once Every 100 Samples or Fewer)
(Real; 4 Bytes) Time of First Sample in Record, in UT Seconds
(Real; 8 Bytes) Initial (Reference) Value for Differential Carrier Phase, in TEC Units
(Real; 4 Bytes) Nominal Sampling Interval, in Seconds
(Integer; 1 Byte) Number of Differential Phase (Including Reference) and L1 Amplitude Samples in Record
(Integer; 1 Byte) Number of L2 Amplitude Samples in Record
(Integer Array; 2 Bytes) Amplitude Samples at L1
(Integer Array; 2 Bytes) Amplitude Samples at L2
(Real Array; 8 Bytes) Differential Carrier Phase Differences with Respect to Reference Sample, in TEC Units

A regular pattern of downward spikes was observed in the signal intensity data for L2 during the campaign. The time interval of these spikes, and their absence in data collected at Hanscom for the same system, indicated that they were interference from a nearby transmitter, broadcasting at 400 MHz. These spikes and local multipath effects were the dominant features during the campaign, as scintillation was only minor.

AFRL personnel presented results of the campaign at the January 2000 National Radio Science meeting.

For corroborative and supplemental studies, the TEC data from the IMS at Thule also were processed for the campaign period, and displays of the vertical-TEC profiles for individual satellites were reviewed in comparison with similar displays for the Qaanaaq data. The two sites are separated by approximately one degree of latitude, at nearly the same longitude, so opportunities for correlation studies exist. Unfortunately, the elevation threshold was 15° for the IMS at the time of the campaign, so coverage to the north was somewhat limited. (See Figure 3.)

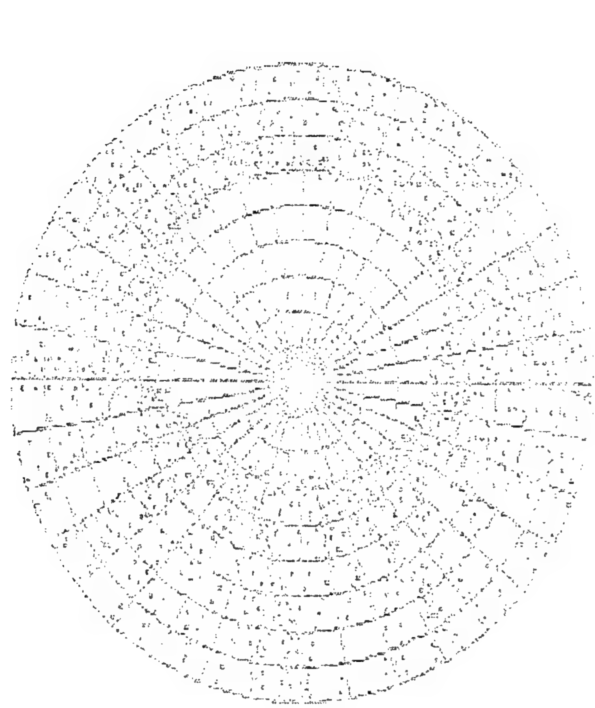


Figure 3. GPS sky coverage over Thule, showing satellite positions at ten-minute intervals, with ten-degree azimuth and elevation gridlines. The actual elevation threshold of 15 degrees eliminates about half of the sky coverage in the northern quadrant, which is a latitude region between about 8 and 18 degrees north of the site.

In expectation of a future deployment to Qaanaaq, the elevation threshold for the Thule IMS was lowered to zero degrees, to increase the amount of overlapped sky coverage between Thule and Qaanaaq. However, the IMS performed poorly and with a great deal of instability with this setting, so an elevation threshold of 14° was established and then decremented in steps. Significant problems occurred with a threshold of ten degrees, so the threshold was raised to 11°. Furthermore, because a pattern of regular outages appeared to be progressing with the GPS constellation, PRN 19 of the GPS constellation was excluded from data collection, reducing the effective number of satellites in view at times when there might be an overload. The situation was monitored until the end of the December 1999, when the elevation threshold was restored to 15°, to minimize potential difficulties associated with the "Year 2000" transition. No problems were associated with the "Year 2000" transition, and the Thule IMS functioned well with the restored elevation threshold.

2.11 Thule GPS Data from Previous Solar Maximum

GPS data from an STEL 5010 receiver for most of the month of October 1989 were processed to provide calibrated equivalent vertical TEC measurements for comparison to model calculations being performed by Boston College. The TEC tabulations also included the coordinates of the ionospheric penetration point. This month of data was chosen because of the high levels of solar and ionospheric activity.

2.12 IMS Modifications

A program of upgrades for the IMS units to implement their specified operational capabilities was commenced in early June 2000. The two major aspects of the upgrades are adaptation and improvement of the communications capabilities to use the Internet-protocol SWN instead of the modem-based AWN, and incorporation of scintillation measurement capabilities. Significant revisions were incorporated into the plan originally developed for the Program Management Review in November 1999, especially with respect to incorporating UHF scintillation capabilities with the IMS L-band scintillation and TEC capabilities. A preliminary design review was conducted at Hanscom on 3 August 2000. The development schedule presented at this review outlined a phased-in implementation of both communications and scintillation capabilities over a two-year period, for all five fielded IMS units, with an early implementation of L-band intensity and phase scintillation indices (S_4 and σ_ϕ) based on the current 2-Hz GPS data. Provisions for automated calibration, including accommodation of the plasmasphere, also were incorporated into this development schedule. A summary milestone chart for this development schedule is presented in Table 2.

By mid-August 2000, a decision to eliminate the second year of funding for the IMS upgrades had been made. Plan revisions to accommodate this decision are currently in progress.

Provisional achievement of one of the communications upgrade objectives was demonstrated at Hanscom by use of a Web browser to retrieve previously generated TELSI data files, allowing an operator to recover data for which an automated transmission had failed. Formal approval from 55 SWXS and the Air Force Weather Agency (AFWA) are pending for this interface method and the details of maintaining previous TELSI data files, so some further development of this process may be required.

An extensive review and evaluation were conducted for the possibility of migrating the Companion PC functions from Windows NT to a Linux computer. The performance advantages of changing operating systems were considered to be minor, while the extent of processing software and procedures to be migrated was significant. Further evaluation has been postponed by the need to accommodate the funding decrease, but developments are still in progress to obtain a more robust computer hardware platform to host the Companion PC operations, for Windows NT, Windows 2000, or Linux.

Table 2. Summary Milestone Chart for IMS Modification

	MILESTONE CHART																							
	2000							2001												2002				
Activity	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
PDR			X																					
CDR							X																	
=== Operations Interface Enhancements ===	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X
TELSI Re-transmission			X	---	X																			
Equipment Status Reports			X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X						
Contingency Equipment Status Reports			X	---	---	---	---	X																
Satellite Exclusion						X	---	X																
Satellite/Receiver Biases			X	---	---	---	X																	
On-site Calibration						X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X			
TEC Multipath Mitigation			X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X	
Plasmasphere Accommodation in Calibrations					X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X
Scale Factor Generator Enhancements	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X		
Remediation for Solar Maximum						X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X	
=== Scintillation Enhancements ===	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X
2-Hz Statistics in TELSI		X	---	---	X																			
20-Hz L-Band Scintillation Spectral Values		X	---	---	---	---	---	---	---	---	---	---	---	---	X									
UHF Sub-system Integration			X	---	---	---	---	---	---	---	---	---	---	---	---	X								
UHF Sub-system Deployments																X	---	---	---	---	---	X		
Amplitude Multipath Mitigation			X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	X	
Y-code Upgrades			X	---	---	---	---	---	---	---	---	---	---	---	---	X								
Increased Sky Coverage			X	---	---	---	---	---	---	---	---	---	---	X										

2.13 Polar Patch Measurements

A project to study patch regions in the northern polar cap was commenced in the summer of 2000. Three GPS receiver systems were deployed to Qaanaaq, Greenland, to conduct TEC and scintillation measurements, in conjunction with other instrumentation being deployed in the vicinity. Three Windows 2000 computers acquired by AFRL were tested with the RTM data collection program and found to be compatible, so the systems all were configured for 20-Hz data collection and archiving, with provisions for remote access by telephone or network, depending on local developments at Qaanaaq. A test period for each computer in its final configuration was conducted at Hanscom before the computers were shipped to Greenland at the end of August 2000.

Several discussions were conducted with AFRL personnel concerning the deployment of antennas for the three GPS receivers, based on previous observations of patch motions (Pedersen et. al., 2000) and an assessment of the terrain and supporting facilities. None of the available sites is close to ideal, so some compromise in observing or operational conditions is likely. The final determination for the deployment configuration will be made at the field site, but the deployment will be in the vicinity of the digital ionospheric sounder system (DISS) rather than near the Danish Meteorological Institute, on the opposite side of the settlement at Qaanaaq.

3. HAARP Topics

Under HAARP, an observatory is being constructed in Gakona, AK, to conduct upper-atmospheric, ionospheric, and radio-propagation research. In addition to a high-power HF transmitter being installed by Advanced Power Technologies, Inc. (APTI), NWRA is facilitating installation of an array of geophysical diagnostic instruments. During this report period, NWRA's HAARP activities involved several of these diagnostics, as well as coordination with other researchers, with APTI, and with the interested general public, as described in the following subsections.

3.1 Classic Riometer

A 30-MHz classic riometer has been operating at Gakona since the summer of 1994 for measurement of radiowave absorption. During this year, NWRA Consultant Jens Ostergaard continued to improve its operation and procedures for use of data therefrom, including extensive servicing of the instrument in late April and early May 2000. The antenna system was checked and all guy wires adjusted and secured, to render the antennas truly vertical. The receiver was calibrated, and the gain of the noise feedback loop was adjusted to improve instrument stability. A new noise source, with built-in attenuators, was used for the calibrations. Comparisons were made with the noise source used previously, so the new calibrations are traceable to the old noise source. Calibration software was rewritten in C and placed on the riometer computer at Gakona. The software is employed to determine the gain and linearity of the riometer, for use by the data-acquisition program. New memory and batteries were installed in the GPS clock, which now should be able to operate reliably through an extended power failure.

Problems with alignment of seasonally adjusted quiet-day curves, discovered in the preceding year, were traced to a software error. The software was corrected, and all affected data in the available HAARP database were replaced during this report period. A quality-assurance parameter now is included in the files as an indicator of invalid or questionable data. The archive from 1 June 1996 through the present is available for display on the HAARP Web site. The edited database through April 2000 was placed on CDs, along with presentation software, and delivered to AFRL.

An example of data from the classic riometer, as routinely displayed on the HAARP Web site, appears in Figure 4. The smooth green line represents the seasonally adjusted quiet-day curve, and the blue line indicates, for comparison, the riometer's detector output, which is proportional to received galactic noise. Bursts (including some above the quiet-day curve) are caused by local or ionospherically propagated radio interference. The difference between the quiet-day curve and the detector output represents ionospheric absorption and is indicated in dB by means of the red curve. During the 36-hour period displayed, absorption abruptly increased from about one dB or less to about five dB at approximately 1700 UTC on 6 April, coincident with onset of a major geomagnetic disturbance. Episodes of lesser absorption occurred approximately 24 hours later.

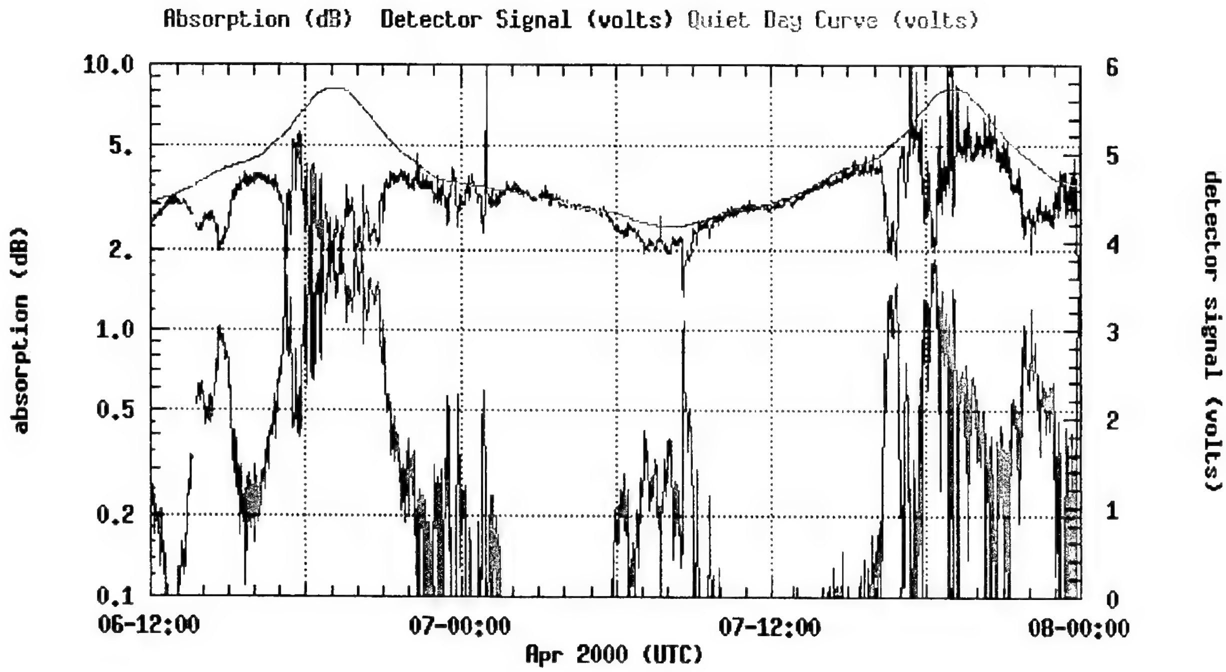


Figure 4. Display, from the classic-riometer page on the HAARP Web site, of ionospheric absorption (red) in dB, along with the galactic radio noise (blue) and comparative quiet-day curve (green) from which it is derived. Near the beginning of the 36-hour period displayed, a major ionospheric/geomagnetic disturbance began at about 1700 UTC on 6 April.

3.2 GPS Receiver for Measuring Absolute TEC

An Ashtech Z-FX Continuously Operating Reference Station (CORS), consisting of a 12-channel GPS receiver and a choke-ring antenna, has been in service at HAARP since 25 March 1999, with data collection being performed by the RTM program. The RTM data collection has been supplemented by a real-time process to convert one-minute reports from the RTM program into "ionospheric penetration-point (IPP)" databases, which become the source of calibrated measurements of absolute TEC displayed on the HAARP Web site. An example of the display is given in Figure 5, which spans the same time interval as the riometer data shown in Figure 4. Nearly simultaneously with the abrupt increase in absorption near 1700 UT on 6 April, TEC dropped rapidly. The drop was followed by a sharp increase near 2100 UT, spanning about five hours during which geomagnetic activity continued. The lesser episodes of absorption near the end of Figure 4 were not accompanied by any significant change in TEC or resumption of geomagnetic activity.

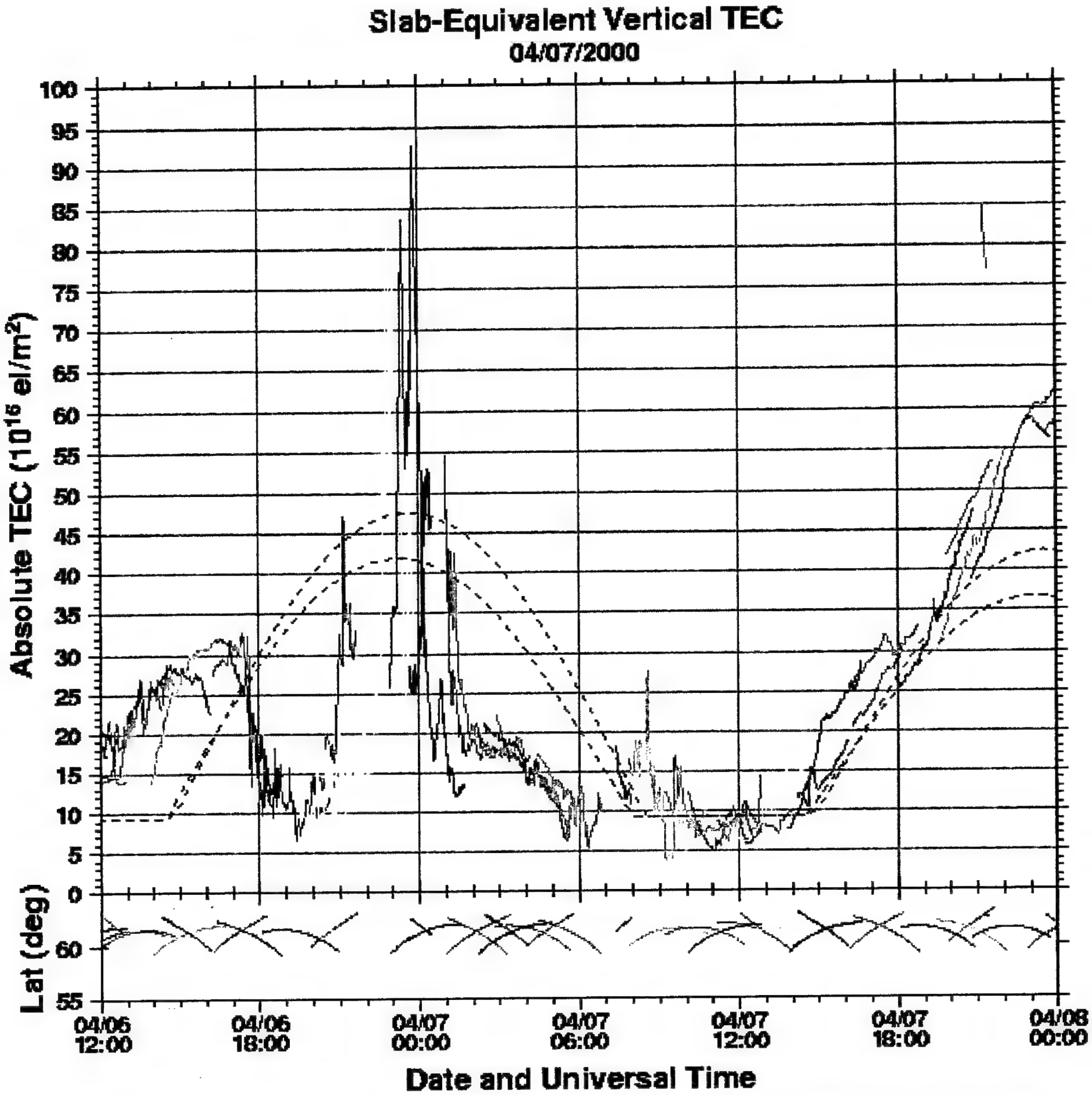


Figure 5. Time history of vertical TEC near Gakona during the same 36 hours for which riometer data are displayed in Figure 4. The decrease starting near 1700 UT on 6 April and subsequent abrupt increase ending near 0200 UT coincided with substantial geomagnetic activity at Gakona.

During this year, we added a capability to the HAARP web site for viewing seven-day and 28-day spans of absolute TEC variation. An example of the seven-day plots was presented in R&D Status Report 12. The 28-day plot ending on the same date (and showing essentially the month of July 2000) appears here in Figure 6. In this and all such displays (36-hour, seven-day, and 28-day), the colored traces show absolute TEC as determined from the CORS two-frequency measurements, and the dashed curves show values calculated from a model using coefficients transmitted by GPS satellites for estimation of TEC by single-frequency users. The latter may be thought of as "quiet-day curves" updated for currently anticipated ionospheric conditions.

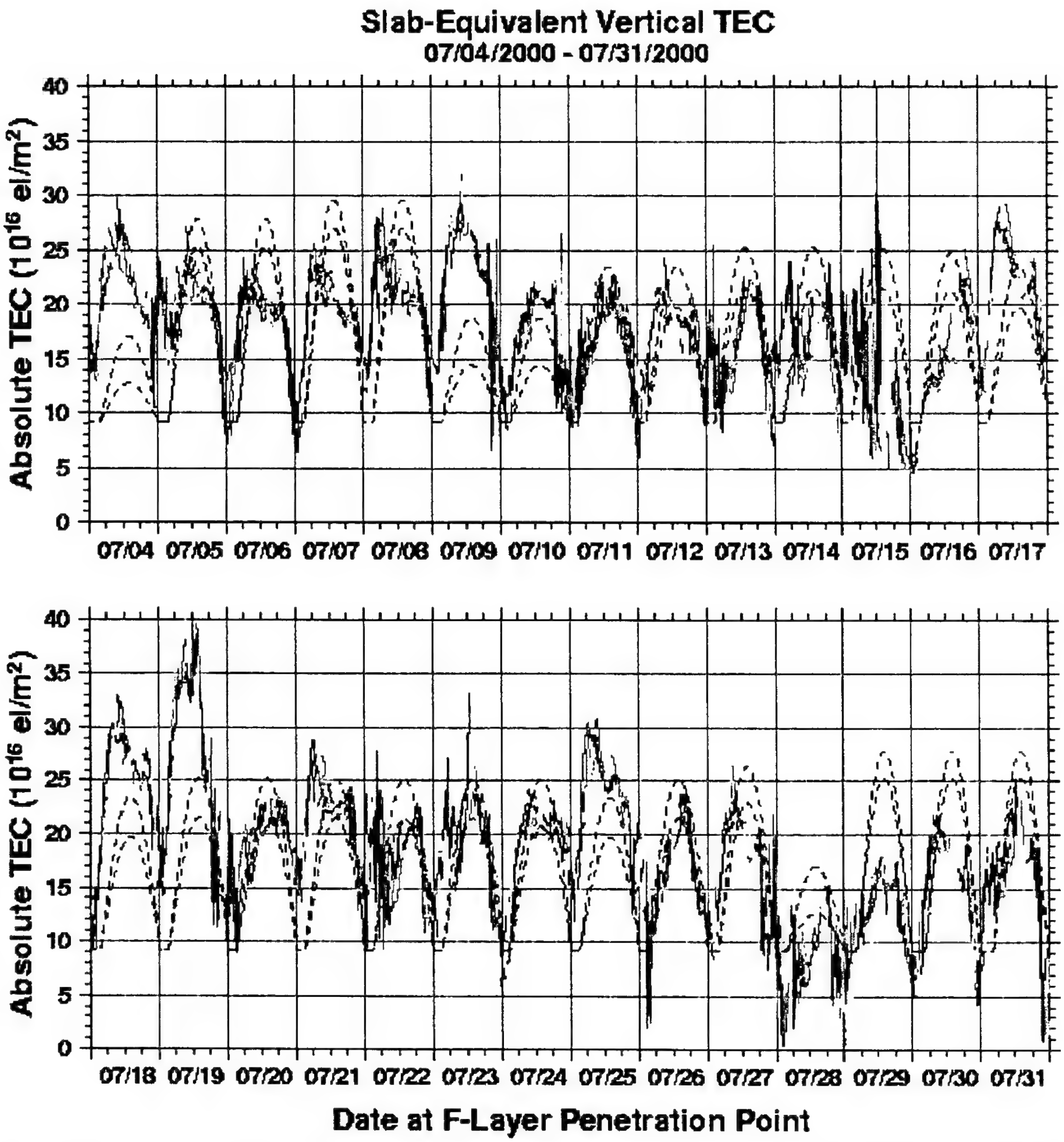


Figure 6. Example of Web display showing 28-day time series of absolute TEC compared with model values (broken curves) computed from coefficients broadcast by GPS satellites. Displays of seven-day spans also are available.

The internal phase-discontinuity correction capabilities of the RTM program were activated at HAARP in mid-1999 after preliminary testing at Hanscom, and the TEC data were examined to evaluate the benefits or problems posed by this setting. Initial results were encouraging and corresponded to the performance obtained for the RTM system at Hanscom. Difficulties became apparent at HAARP as the ionospheric activity increased, however, to a degree that the real-time TEC reports could not be considered valid. Accordingly, we de-activated the internal phase-discontinuity correction at HAARP in autumn 1999. Further investigation of the parameters used in the correction algorithm may be required, or we may activate the correction only on a seasonal basis.

Near the conclusion of the HAARP campaign in late October 1999, several studies were conducted into possible interference effects of the aircraft-detection radar on the Ashtech GPS receiver. GPS data taken during preliminary trials of the radar showed no effects, even when examined at the most detailed sampling interval available (one second), and the full set of radar tests on the succeeding day also showed no effect in the GPS data.

In early October 1999, bias-level variations became apparent more frequently, and investigations were performed to determine the nature of the variation. A problem with the antenna cabling was suspected because similar symptoms had been encountered at Hanscom with various GPS receivers. To ameliorate the problem and to provide further information for isolating the cause, the schedule of bias calibrations was changed from once every two weeks to twice weekly, and the average bias levels are being recorded. The magnitude of the bias variations was about five TEC units over a period of about a week. A field visit was accomplished in late January 2000 to investigate the bias variability. An unnecessary connector was removed from the antenna cabling, and the situation appears to have improved, but the schedule of bias calibrations is being maintained at twice weekly, to monitor possible bias variability.

The computer supporting the RTM data collection appeared to be experiencing some performance difficulties during the later part of 1999, requiring manual restarts either remotely or by personnel at the HAARP site. In many cases, a number of the intermittent one-minute processing operations were found halted by an untraceable error and awaiting operator intervention to be terminated, but in other cases, the system was inaccessible to remote access and unresponsive locally. Furthermore, it is not apparent why the heartbeat rebooter is not restarting the system in these circumstances; especially after a secondary process-verification procedure was installed in mid-November 1999. This computer was examined during the January 2000 field visit, but no specific cause for these problems could be ascertained. A network-accessible power controller was installed during a site visit in May 2000 to eliminate the need to contact on-site personnel to restart the computer. The selected device was not obtained until after the January 2000 site visit. Additional arrangements with network-management personnel for the site were required to enable Telnet access to the network power controller, which has been utilized successfully. An automated method for detecting and correcting the halted processing operations is still under investigation, but an operator-initiated process for easily eliminating the halted processes has been implemented.

Because other processing also has been halted by similar errors, maintenance diagnostics were performed for the computer hard drive in mid-August 2000, to alleviate possible virtual memory problems. The conditions have not been completely resolved since the maintenance activities.

In January 2000, procedures for performing bias calibrations for RINEX data files were revised to utilize the most recent version of the bias calculation program. This version allows some additional weighting and selection options, but retains the central mathematical algorithm. Additional procedures for performing bias calibrations are being revised to utilize only complete GPS satellite passes. The current process utilizes data for a single day (in Universal Time), producing pass fragments of varying length at the beginning and end of the day. This technique can produce inconsistent results from phase averaging. The utilization of complete passes previously had been implemented for IMS data processing, with favorable results, but the implementation for the RTM will need to be different.

Soon after the computer maintenance activities in August 2000, the equivalent vertical TEC profiles were observed to display a large degree of variability superimposed on the normal diurnal

pattern. With the completion of a full day of data collection for this phenomenon, it also was observed, from the Web page displays, that the sky coverage consisted of only about half of the sky. Contact with on-site personnel confirmed the conjecture that the GPS antenna structure had toppled from high-speed winds at the site, resulting in severe multipath for the unorthodox antenna orientation in addition to the excluded region of coverage behind its choke-ring plane. The antenna structure was re-erected and fastened more securely. Subsequent examinations of the multipath patterns indicated that the possible damage to the antenna cable from this incident was minimal, but further examination will be conducted during the next site visit.

Ionosonde data processed by the Center for Atmospheric Research at the University of Massachusetts at Lowell are reported on the HAARP Web site and contain values of vertical TEC derived from bottom-side sounder data and a topside model. Since early December 1999, daily summaries of these derived vertical-TEC values have been retrieved from the HAARP Web site for comparison with slab-equivalent vertical-TEC values measured on GPS ray paths having elevation angles greater than 65 deg. Additional quantitative comparisons are performed for days on which HAARP GPS calibrations are conducted, with the ionosonde and GPS TEC values combined onto one spreadsheet. As illustrated in Figure 7, the values derived from the ionosonde often are substantially smaller than those measured by means of GPS. A possible explanation for the discrepancy is that the model used to extend the ionosonde data insufficiently accounts for topside plasma. To date, this possibility has not been definitively explored.

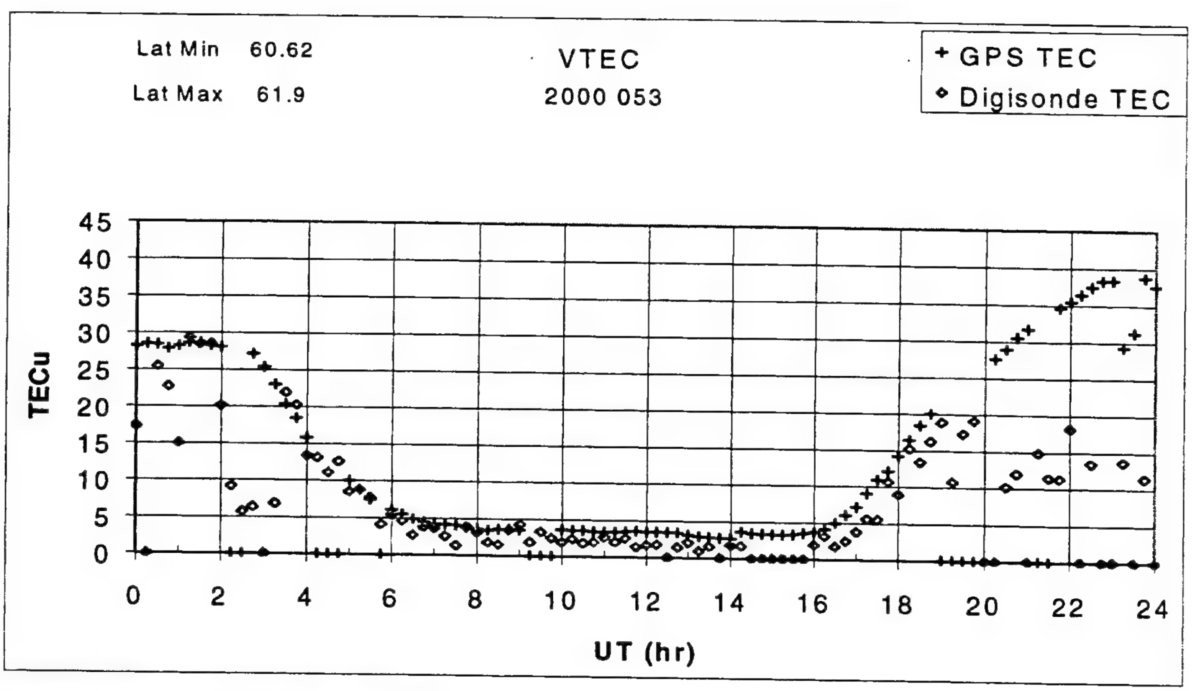


Figure 7. Vertical TEC values for 22 February 2000, UT, measured by means of GPS (+) and estimated by means of the Digisonde and a topside model (◦), showing substantial underestimation by the latter. (Values on horizontal axis indicate missing data samples for the corresponding 15-minute period.)

3.3 GPS Determinations of Position

Developments are in progress for using GPS pseudorange measurements reported by the RTM system to calculate position estimates, using the generic algorithm for GPS position determinations. A program previously developed for calculating GPS satellite sky positions from RINEX navigation files was adapted to report the geocentric satellite positions required for the position calculations, and other modules were developed for selection of the quartets of satellites and their associated position estimates. Further routines for the calculation of position dilution of precision (PDOP) were completed, and some refinements were incorporated into the position determination algorithm to implement the clock drift corrections.

Preliminary tabulations of position estimates derived from each of the two GPS frequencies have been generated for test sites. The data collection parameters recorded by the HAARP RTM systems were augmented by the pseudorange values in early August 2000, to allow position determinations at that site, but further testing and procedure development are required to automate the calculations for daily reports and displays.

3.4 Receivers of Transit-like Signals for Recording Latitude Scans of Relative TEC

An NWRA ITS10S coherent radio receiving system has been operating at Gakona since 23 December 1998 to record dispersive (differential) phase between the mutually coherent VHF and UHF signals transmitted from Oscar-class Transit satellites in the Navy Ionospheric Monitoring System (NIMS). The dispersive phase, recorded at 50 samples per sec (sps) during passes of approximately 15 minutes duration, provides latitudinal scans of relative TEC over Alaska, smoothed to one sps and referenced to the minimum value recorded during the pass. An example of such a record of relative TEC and its attendant geometry were presented in Status Report 6. A second ITS10S has been operating at the Silver Fox Roadhouse, on the Alaska Highway about 20 miles south of Delta Junction, since 23 September 1999. This "Delta" location is 1.5 deg of latitude north of Gakona and 1.2 deg of longitude west.

A third ITS10S is operated normally at NWRA's main facility in Bellevue, WA, as a status monitor of Transit-like satellites and as a test-bed for ITS10S refinements and trouble-shooting when necessary. As of this writing, it is operating in a more radio-quiet location at Arlington, some distance north of Bellevue, for comparative tests of various antenna configurations. Ground screens measuring 10-by-20 feet are employed at the Gakona and Delta sites. Recently we have been asked to field an ITS10S at Cordova, AK, replacing a NIMS receiver presently operating there for the Naval Research Lab (NRL). The installation must include an antenna on a school-building roof that cannot accommodate a sizeable ground screen.

All three operating ITS10S receivers and one stored in Bellevue as a spare have been refined to auto-tune to Russian and other U.S. satellites that transmit Transit-like signals from similar orbits (all near-polar and near-circular at approximately 1000 km altitude). A fifth ITS10S operated briefly some years ago at Thule, Greenland, under a previous contract and subsequently was stored at Hanscom AFB for an extended period. After becoming non-operable due to a failure of undetermined origin, it was been shipped to Bellevue and is in storage there, without any of the HAARP refinements.

The purpose of deploying instruments capable of measuring dispersive phase between signals radiated from Transit-like satellites is to invert the resulting relative TEC records tomographically to produce two-dimensional (latitude/altitude) images of ionospheric plasma density. For this purpose,

we anticipate collaborating with researchers from the University of Alaska Fairbanks' Geophysical Institute (UAF/GI), who are installing such receivers at four sites north of Delta, approximately along the Gakona meridian, spanning from Poker Flat, near Fairbanks, to Kaktovik, on the Arctic coast. During this report period, we conducted a proof-of-concept test of the NWRA tomographic inversion processor, combining TEC data from Delta and Gakona with two such records obtained from NRL's NIMS receiver at Cordova. The resulting rudimentary (three-station) tomographic image from one of those passes is shown in the bottom panel of Figure 8, obtained by inverting the three records of relative TEC shown in the top panel of the same figure.

When augmented by means of TEC data from additional stations, such as those being deployed by UAF/GI, such images will permit study of both the background ionosphere and plasma features imbedded in it. Even without the details that will be available from the higher-resolution (multi-receiver) images, such records permit latitudinal extension of ionospheric parameters measured at the HAARP site in Gakona. For instance, Figure 9 shows the F-layer critical frequency (top panel) and F-layer peak height (middle panel) scaled from the image in Figure 8 compared with the point values (asterisks) measured by means of HAARP's digital ionosonde. Vertical integration through the image produced the latitudinal scan of absolute TEC shown in the bottom panel of Figure 9, effectively extending the measurements of absolute TEC made in the vicinity of Gakona by means of the CORS/RTM there.

Conversion from relative slant-path to absolute vertical TEC may be performed most reliably by integrating vertically through tomographic images of plasma density, as in Figures 8 and 9. Given a sequence of slant-path measurements from a single station, an approximate conversion can be made under sufficiently simple ionospheric conditions. Such approximate conversion relies on an ad hoc assumption, usually that of a slab-like ionosphere devoid of horizontal gradients. Even with such an assumption, one needs additional information to account for the unknown offset inherent in records of relative TEC (stemming from the $n\pi$ ambiguity in the dispersive phase actually measured). As described in Status Reports 10 and 11, we explored two methods for deriving such information and now have implemented a hybrid of the two.

In the method now implemented, ITS10S data from both Gakona and Delta are transmitted to the RTM system at Gakona whenever Transit-like satellite passes are completed, and these relative-TEC measurements are calibrated against one another and against the current GPS TEC measurements available on the RTM computer, even before the latter appear on the HAARP Web site. We also developed additional procedures to maintain distinct report files for the calibrated ITS10S TEC data and to isolate "orphan" cases, in which the ITS10S measurements did not satisfy proximity conditions relative to GPS ionospheric penetration points in either space or time to allow a GPS-aided calibration.

Listings of calibrated slant TEC and equivalent vertical TEC from the ITS10S measurements are generated for display on the HAARP Web site, with the equivalent vertical TEC appearing on the same plot as the equivalent vertical TEC data derived from the GPS measurements. In Status Report 12, we presented an example as a time series over a 36-hour span including all of 21 August 2000, UT. All such plots (as well as those showing GPS-derived TEC over spans of seven and 28 days) may be presented on the Web site also as functions of local time at the 350-km ionospheric penetration points (IPPs) of the lines of site. An example appears in Figure 10 for 36 hours including all of the IPP date 21 August 2000.

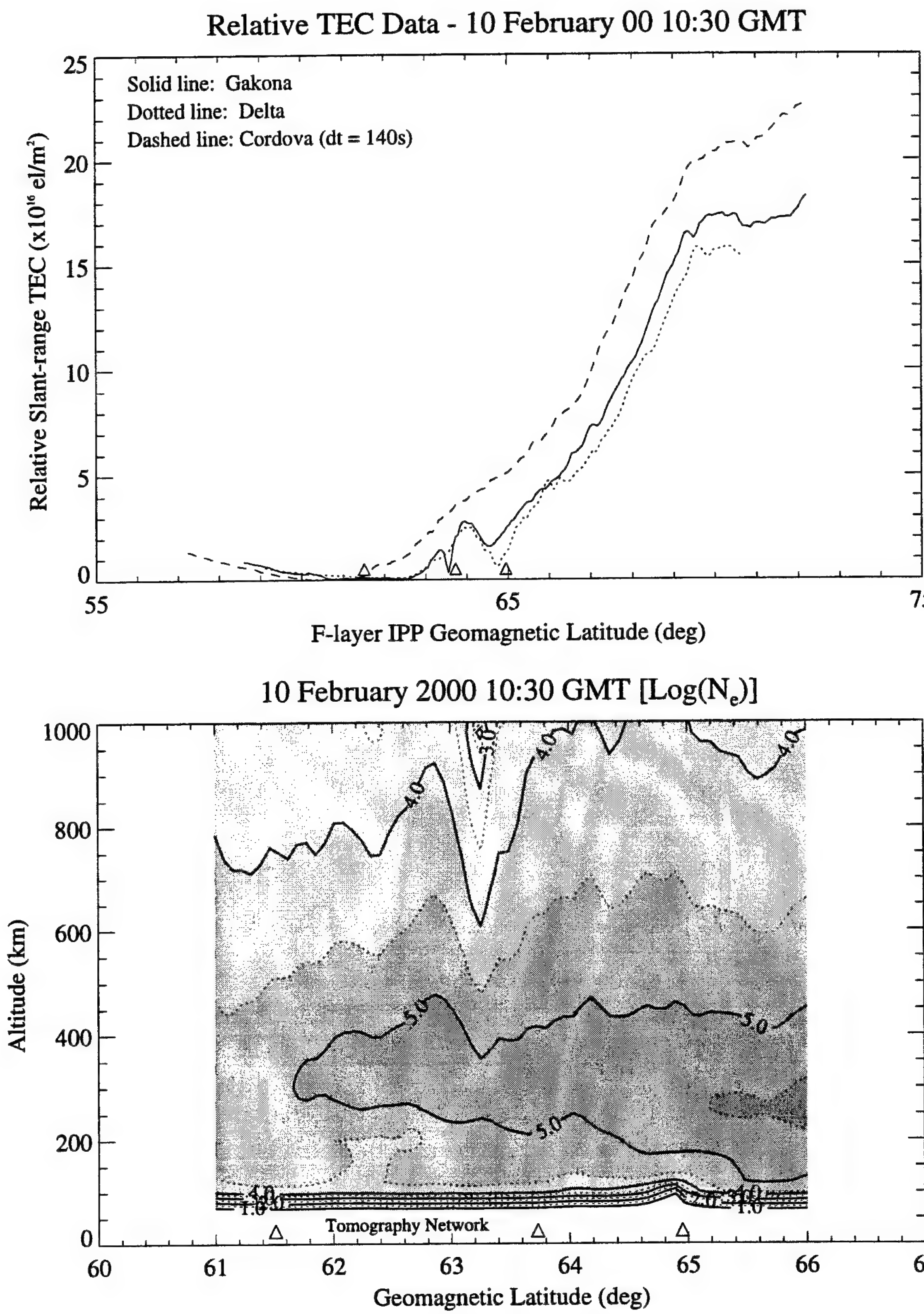


Figure 8. Rudimentary example of an F-layer image (bottom) produced from three records (top) of relative TEC, recorded at Cordova, Gakona, and Delta, AK, as indicated by the triangles on the abscissas.

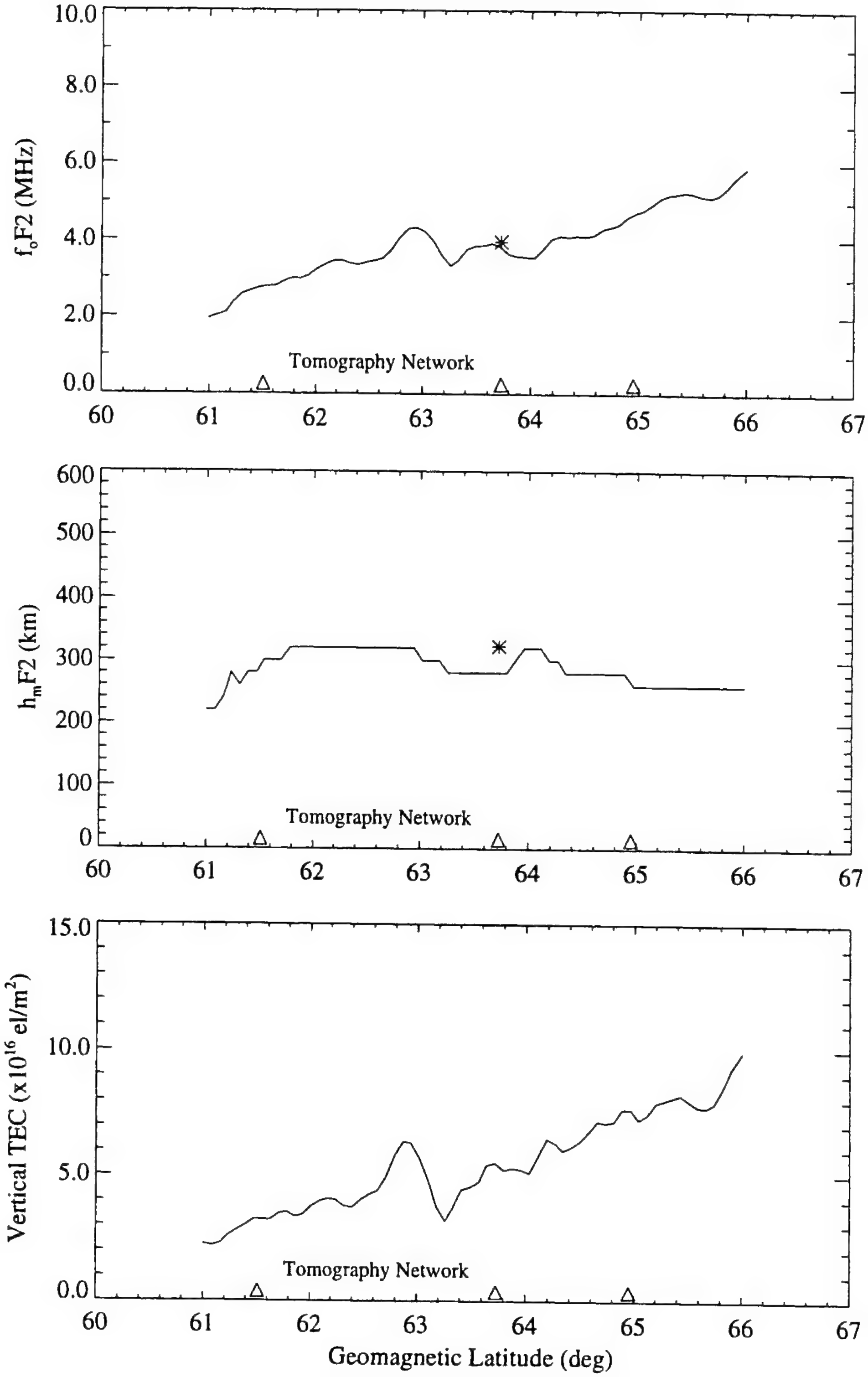


Figure 9. Latitude distribution of F-layer critical frequency (top) and peak height (center) scaled from tomographic image in Figure 8, compared with values measured (*) at Gakona by means of the digital ionosonde there. Bottom panel shows latitude distribution of absolute TEC obtained by integrating vertically through the image.

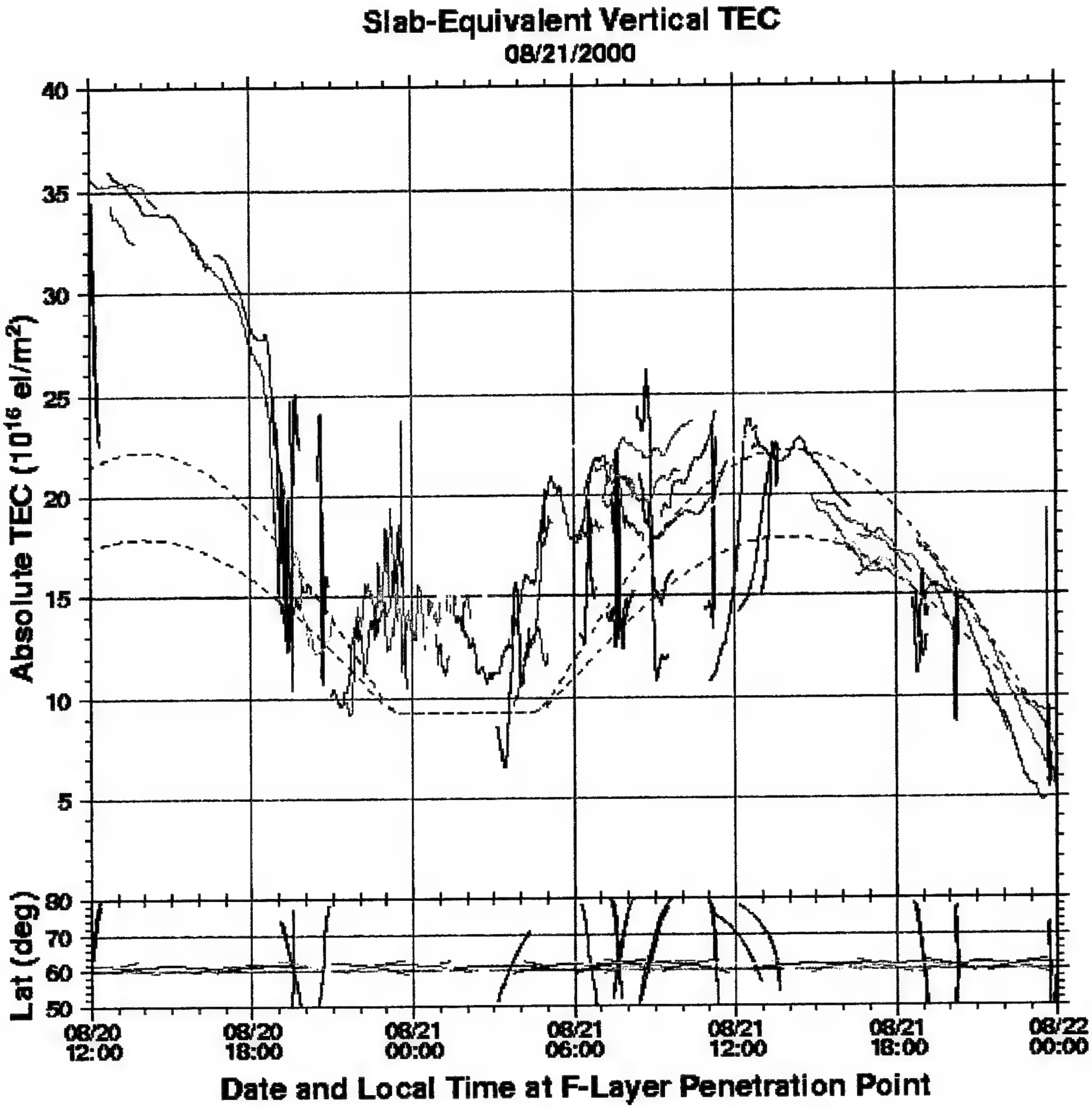


Figure 10. Example of Web display overlaying rapid latitudinal scans of absolute TEC during overpasses of Transit-like satellites (black traces) on continuous time series of values from high-elevation GPS ray-paths (colored traces).

3.5 All-sky Imaging Camera

During June and July, NWRA Student Intern Tyler Wellman worked with AFRL personnel at Hanscom AFB. His principal project for the summer was to create a Java applet to display false-color images from the All-Sky Imaging camera in real time. The research of AFRL Scientist Todd Pederson, who previously had developed a program to produce such images, will be facilitated by the portability afforded by a Java applet capable of displaying them.

Mr. Wellman first modified the control code of the All-Sky Imager to produce condensed JPEG files containing eight kilobytes (kb) of data for Internet display and/or real-time download over a

narrowband connection. He then developed the applet to provide a capability to display the JPEG files on the Web. The files contain such information as the latitude and longitude of the camera, the wavelength of the filter (red, green, blue, or infrared) employed, and the time of data recording. The Java applet reads the data stored in the JPEG file and displays the image via a Web browser with the time, location, and wavelength written over it. It also displays the stored image in red, green, blue, or gray, depending on the filter employed.

In early August, Mr. Wellman participated in HAARP's Summer 2000 Faculty/Student Science Campaign. Thereafter, he worked at the HAARP site in Gakona through mid-August, including completion of the applet.

3.6 Coherent Backscatter Radar

NWRA Consultant John Rasmussen collaborated with experimenters who intend to employ a 139-MHz backscatter radar as a HAARP diagnostic toward placement of the radar's antenna array and instrument shelter. The antenna area was defined, and support structure for the antenna array has been designed. Mr. Rasmussen has initiated discussions with a local contractor, Ahtna Construction, for installation of the array structure. Following laying of a foundation for the instrument shelter, the shelter was erected. Under Mr. Rasmussen's supervision, NWRA Student Intern David Bruington installed instrument racks and cabinets.

3.7 Powerful Diagnostic Radar

A panel, including five NWRA consultants, formulated recommendations for a powerful diagnostic radar (PDR) at Gakona. Following an organizational meeting of co-chairs Brenton Watkins and William Gordon in San Francisco in December 1999, the expert panel of radar engineers and scientists was convened to work out a recommended approach to acquisition of a PDR and to estimate the associated cost. In addition to Drs. Watkins and Gordon and with NWRA Consultant A. Lee Snyder serving as its executive, the panel consisted of radar engineers David K. Barton and Allan Schell and radio scientists Frank T. Djuth and Michael C. Kelley. The panel's report was completed and delivered to the HAARP Program Managers, Paul Kossey of AFRL and Ed Kennedy of ONR/NRL, in August 2000. Dr. Snyder also prepared a brief description of the PDR as it might be acquired for use at Gakona, for inclusion in the *HAARP Diagnostics Brochure* prepared by Mr. Rasmussen.

3.8 Diagnostic Infrastructure

Working under the supervision of Helio Zwi, of APTI, Mr. Bruington created software for displaying data from multiple HAARP instruments, such as the magnetometer, the classic riometer, and the Digisonde, on a single set of axes for convenient comparison of varied ionospheric phenomena. NWRA also provided instrumentation to allow distribution of synchronization pulses and a 1-MHz frequency standard over fiber lines from the Operations Center to the optical shelter.

Dr. Snyder oversaw contractor efforts to complete the new HAARP Operations Center. Completion of exterior painting closed out the last item on the contractor's punch list. Mr. Rasmussen and Dr. Snyder, along with APTI, AFRL, and NRL personnel, participated in the transfer of diagnostic instrumentation and installation of furniture in the new Operations Center. Some diagnostic instrumentation must remain in one of the old operations-center trailers, and considerable work remains to complete this consolidation and the removal of remaining material. Completion of this effort should allow for the return of at least two of the trailers. The construction

contract for the Operations Center includes a one-year warranty. Several items needing attention have been discovered, discussed with APTI personnel, and hopefully can be repaired under the warranty.

Working with inputs from the HAARP management team, APTI personnel, and individual diagnostic investigators, Mr. Rasmussen developed a plan for expansion of roads and pads at the HAARP site to meet increased demand for additional instrumentation. An integrated product team (IPT) has been established to coordinate these developments.

3.9 Other Coordination of Diagnostics and Scientific Collaboration

Mr. Rasmussen and Dr. Snyder worked with Michael McCarrick of APTI and with HAARP program management to finalize the *Research Guidelines* that were introduced at the HAARP Diagnostics Workshop held at Lake Arrowhead, CA, in May 1999. The guidelines include a statement of "Proposal Requirements for HF-transmitter-related Experiments" and a definition of "HAARP Data Rights." They also describe procedures for requesting site-visit approval, temporary instrument installation, and the operation and temporary removal of permanent HAARP diagnostic instruments.

Mr. Rasmussen supported overall diagnostic efforts by completing development of the *HAARP Diagnostics Brochure*. The brochure, which contains descriptions of sixteen diagnostic instruments, was delivered to the HAARP program office on a zip disk. Mr. Rasmussen also supported development of the agenda for the Year 2000 RF Ionospheric Interactions Workshop, which was held once again in Santa Fe, NM, and represented diagnostic interests at several Program Management meetings during the year.

3.10 Broader Scientific and Educational Collaboration

At the RF Ionospheric Interactions Workshop, Michael Kelley (Cornell University), acting as an NWRA consultant, led discussions regarding use of the HAARP facility for aeronomic research. The topic that seems most likely to provide early results involves unique aspects of the summer polar mesosphere. A second involves the storm-time trough. Along with Consultants Rasmussen and Snyder, NWRA Sr. Research Scientists Edward Fremouw and James Secan participated in the workshop. Mr. Rasmussen presented an overview of HAARP diagnostics, while Dr. Fremouw and Mr. Secan joined with Paul Bernhardt and Craig Selcher, of NRL, in describing TEC tomography as an ionospheric diagnostic.

Dr. Snyder initiated discussion of HAARP activities with Syun-Ichi Akasofu, Founding Director of the new International Arctic Research Center (IARC) at UAF. As a result of those discussions, Dr. Snyder drafted an announcement of a HAARP Summer 2000 Student/Faculty Research Campaign, which appeared on 21 December 1999 in the Student Opportunities section of EOS (the newsletter of the American Geophysical Union). The campaign took place during the period 31 July through 10 August 2000.

Along with Dr. Kennedy, Dr. Snyder and Mr. Rasmussen later met with Dr. Akasofu and with Joseph Kan, Dean of the UAF Graduate School, to establish a relationship between HAARP and UAF/IARC. Emphasis was placed on an initial program of collaboration between IARC personnel and researchers from other organizations, intended to bear scientific fruit within 18 months. An objective is to use this initial program to develop multi-disciplinary teams of scientists to undertake

polar aeronomy and radio science projects that exceed the capability and/or resources of any one participating research organization.

As reported in Annual Report No. 2, NWRA Consultant Spencer Kuo last year collaborated with Dr. Kossey and other AFRL researchers and with M.C. Lee, of the Massachusetts Institute of Technology, in a theoretical study of ELF and VLF wave generation in the heating-wave-modulated polar electrojet. Their linear theoretical analysis indicated that a stimulated thermal instability is excited and that this instability introduces an electron-temperature modulation more effectively than does the passive ohmic-heating process (Kuo et al, 2000). The thermal instability is expected to improve considerably the intrinsic efficiency of ELF and VLF wave generation by the amplitude-modulated HF heating wave. The generation efficiency and signal quality depend on the HF-wave modulation scheme.

Acting as an NWRA consultant, Sanghum Lee, a student of Prof. Kuo at Polytechnic University in Farmingdale, NY, is extending the analysis into the non-linear regime by conducting a numerical study of ELF/VLF generation by electrojet modulation via an X-mode HF heating wave. Mr. Lee is examining four amplitude-modulation schemes investigated in the linear analysis: (1) rectangular wave, (2) beat wave, (3) rectified half wave, and (4) triangular wave. Presently under investigation are the dependencies of the ELF/VLF radiation intensity on the power, modulation frequency, and modulation scheme of the HF heating wave.

Initial results indicate that ELF radiation intensity (at 100 Hz) increases abruptly when the power of the heating wave exceeds a critical level. The critical level varies with the modulation scheme and frequency. The relative efficacy of the four modulation schemes is being investigated in the range from 100 to 5000 Hz by comparing the spectral intensities of the fundamental and the second and third harmonics of the generated ELF/VLF radiation. In accord with the linear analysis, initial numerical results indicate that the rectified half-wave is the most efficient modulation, while the beat wave generates the signal of highest quality (i.e., having the least harmonic content).

3.11 Educational Efforts and Public Relations

Dr. Snyder presented a talk at the University of Massachusetts' Center for Atmospheric Research on 2 December 1999. He and Mr. Rasmussen participated in planning the annual open house at the HAARP field site near Gakona, as well as the facility visit by senior Department of Defense (DoD) officials. These events were planned and conducted to promote program awareness, understanding, and the potential for innovative research for DoD applications. Mr. Rasmussen and Dr. Snyder provided support during the facility visit, which took place during the period 7 through 10 July. NWRA Student Interns Bruington and Wellman and Consultant William Gordon participated in the open house, which took place on 12 and 13 August 2000.

3.12 Coordination with APTI

Dr. Snyder participated with APTI, NRL, and other personnel in planning transfer of a surplus AN/TPS-63 radar currently located with a USMC unit in Virginia Beach, VA, to HAARP and to define the site infrastructure upgrades needed to accommodate it. The AN/TPS-63 is a coherent radar capable of detecting and tracking a 0-dBsm target at a range of 160 nautical miles, and it includes an identification-friend-or-foe (IFF) interrogator. HAARP's radar-surveillance capability is intended to recognize a need to shut down the HF transmitter should an aircraft fly through a cylinder having a diameter of ten nautical miles and extending from the surface to an altitude of

50,000 feet. Combination of the AN/TPS-63's IFF interrogator and its facility for ground-clutter suppression with its sensitivity will provide such a capability.

Three 486 computers used to process riometer and ELF-receiver data encountered Y2K problems. Mr. Rasmussen worked with APTI personnel to solve the problems by means of "Y2K-Fix" boards manufactured by Evergreen Technologies. Numerous items of Government property were turned in to Elmendorf AFB, AK, during a cleanup of the HAARP site in June. Dr. Snyder coordinated with APTI and AFRL personnel to facilitate the cleanup. Work continues to accomplish careful removal from the site of 380 pounds of freon, a hazardous chemical that must be disposed of in a responsible and approved manner.

3.13 Other HAARP Planning and Coordination

To continue approval for operation of HAARP's HF transmitter array, the Federal Aviation Administration (FAA) requires designation of a HAARP Controlled Firing Area (CFA). Dr. Snyder is providing support for drafting and coordinating documentation associated with the CFA. He and Mr. Rasmussen participated in several HAARP program-planning meetings during the year.

4. Publications and Presentations

Fremouw, E.J., J.A. Secan, P. A. Bernhardt, and C. Selcher, "Imaging of Large-scale Structures in the Modified and Unmodified Ionosphere," RF Ionospheric Interactions Workshop, Santa Fe, NM, April 2000.

Kuo, S.P, M.C. Lee, Paul Kossey, Keith Groves, and J. Heckscher, "Stimulated Thermal Instability for ELF and VLF Wave Generation in the Polar Electrojet", *Geophys. Res. Lttrs.*, *27* (1) , 85-88, 2000.

Rasmussen, John, "Diagnostics Overview," RF Ionospheric Interactions Workshop, Santa Fe, NM, April 2000.

Snyder, A. Lee, " Ionospheric Generation of Radio Waves and the Detection and Characterization of Underground Facilities,"Lecture presented at the University of Massachusetts' Center for Atmospheric Research on 2 December 1999.

References

Kuo, S.P, M.C. Lee, Paul Kossey, Keith Groves, and J. Heckscher, "Stimulated Thermal Instability for ELF and VLF Wave Generation in the Polar Electrojet", *Geophys. Res. Lttrs.*, *27* (1) , 85-88, 2000.

Pedersen, T.R., B.G. Fejer, R.A. Doe, and E.J. Weber, "An incoherent scatter radar technique for determining two-dimensional horizontal ionization structure in polar cap F region patches", Journal of Geophysical Research, Vol. 105, No. A5, pp. 10637 – 10655, May 1, 2000.

Appendix

Consultant Support to the High Frequency Active Auroral Research Program Annual Report No. 3

John E. Rasmussen
and
Arnold L. Snyder, Jr.

Introduction: Consultant support to the High Frequency Active Auroral Research Program (HAARP) began in July 1996 for Mr. Rasmussen and in August 1996 for Dr. Snyder and has continued to date. The consultants combine experience and understanding of the Department of Defense acquisition process, facility planning, impacts on ionosphere-dependent and -affected systems, auroral and ionospheric physics, and diagnostic instrumentation for upper-atmospheric observations. This combination of skills has proven beneficial to HAARP in program planning and management and in coordination with prime contractors and subcontractors and with various elements of the scientific community. A summary follows for each of the major activities undertaken in support of HAARP by Mr. Rasmussen and Dr. Snyder during the period 1 September 1999 through 31 August 2000.

Planning and Implementation of Site Infrastructure: The acquisition and bringing on line of a new Operations Center was a major activity during this reporting period and significant achievement for the HAARP program. Dr. Snyder has served as the Program's representative on the Integrated Product Team (IPT) for the new Operations Center, coordinating the development between the HAARP management team and the prime contractor (Advanced Power Technologies, Inc.). Construction began in early July 1999 and was essentially complete on 10 January 2000. As the Program's representative on the IPT, Dr. Snyder coordinated government positions and resolved issues during construction including participation in the Building Completion Inspection.

Mr. Rasmussen and Dr. Snyder served as members of the IPT for the Operations Center Control Room with responsibility for planning the layout, furnishings, power, and communications. In collaboration with the HAARP management team, they finalized the layout and associated furnishing requirements and supported the procurement of the furnishings and the installation in the Operations Center that was completed in July 2000.

Mr. Rasmussen also served as a member of the IPT for the move from the old temporary trailer facility into the new Operations Center. He was responsible for planning the transfer of diagnostic operations to the new facility. In cooperation with APTI, the diagnostics were transferred in early July and the remainder of the transfer, including the HF transmitter control, by mid August. The move took place with essentially no disruption to the operational capabilities of the installation.

A coherent aircraft-alert radar at the HAARP field site is needed for detection and tracking of general-aviation aircraft flying at low altitudes. Dr. Snyder has led the program to provide reliable radar coverage through either an upgrade to the existing radar or the acquisition of a coherent radar suitable for this task. ISSO has arranged for HAARP to acquire a surplus AN/TPS-

63 radar located at a USMC unit in Virginia Beach, VA. The AN/TPS-63 is a coherent, 160 nmi radar against a 0 dBsm target and it includes a provision for an identification friend or foe (IFF) interrogator. Dr Snyder has worked with ISSO, APTI and the HAARP management to plan for the transfer of the radar to HAARP and to define the site infrastructure upgrades needed to accommodate the radar. Three-phase power for the radar is to be installed in October 2000 and the radar installation is scheduled for completion by January 2001.

During the construction of the HAARP facility, a significant amount of excess material has been created necessitating a major site clean up. Together with Mr. Laycock (AFRL), Dr. Snyder planned and coordinated the cleanup, which was completed in June 2000. The action included the disposal of excess items such as the former antenna-matching units, diesel-electric generators, a heating boiler unit, holding tanks, pumps and scrap metal.

Planning and Implementation of Diagnostic Instrumentation: Mr. Rasmussen is responsible for coordinating the development of HAARP diagnostics and for planning the development of facilities to support present and future diagnostic needs. This activity included coordinating a plan to extend the current road 0.5 miles and install two additional instrument pads with power and communications. The road extension is scheduled to be completed by June 2001. In addition, during this reporting period emphasis has been on planning and installing the infrastructure required for the 139 MHz Coherent Backscatter Radar. This includes power, communications, shelter and the antenna array support structure. A 10-foot by 24-foot arctic shelter was acquired by NWRA and was installed in August 2000. The power, communications and antenna support structure are scheduled for completion in October 2000.

Dr. Snyder has served as the Incoherent Scatter Radar Panel Executive, organizing four meetings, gathering panel member comments, editing the final Panel report and delivering the product to the sponsors (AFRL and NRL). The Panel was formed to recommend an approach and estimate the associated cost for the acquisition of a powerful diagnostic radar for HAARP. The Panel was co-chaired by Drs. Brenton Watkins and William Gordon and included David Barton, Allan Schell, Frank Djuth and Michael Kelley.

Mr. Rasmussen coordinated the development of a HAARP Diagnostics Brochure that includes a general description of the facility, a table briefly describing the capabilities of each instrument and a section with individual descriptions of each diagnostic. Hard copies and an electronic copy were provided to AFRL and NRL and the entire brochure is available on the Internet at http://w3.nrl.navy.mil/pdoc/diagnostics.doc.

Mr. Rasmussen also represented HAARP diagnostics at Program Management and Strategic Planning meetings during the year to define program needs and priorities.

Coordination and Support of Scientific Research: Dr. Snyder and Mr. Rasmussen continue to assist the Program with coordination of HAARP research activities. A new initiative this year was the Summer 2000 Student/Faculty Research Campaign, which was sponsored jointly by HAARP and the University of Alaska Fairbanks. Dr. Snyder developed the nine-day program in cooperation with HAARP management and the UAF's Geophysical Institute. He also chaired sessions that included the Faculty science presentations and the Student experiment summaries. Mr. Rasmussen provided a presentation on HAARP Diagnostics.

Dr. Snyder has also provided coordination and planning to establish a HAARP relationship with the University of Alaska Fairbanks International Arctic Research Center. Discussions were held with the Center's Director, Professor S.-I. Akasofu to document the proposed program content and produce an associated statement of work. The approach is to use this initiative to develop multi-disciplinary teams to undertake polar aeronomy and radio science projects that exceed the capability and/or resources of any one participating university or organization. It is expected that the relationship will be finalized by November 2000.

In addition to the foregoing, Mr. Rasmussen and Dr. Snyder assisted the Program in review of proposals for experiments during HAARP field campaigns and participated directly in campaigns by coordinating facilities for instruments, including shelter, power, and communications.

Public and Educational Outreach: Dr. Snyder and Mr. Rasmussen participated in planning of the annual open house at the HAARP field site near Gakona, AK, as well as the facility visit by senior Department of Defense (DoD) officials. These events were planned and conducted to promote program awareness, understanding, and the potential for innovative research for DoD applications.

Dr. Snyder presented a talk, "Ionospheric Generation of Radio Waves and the Detection and Characterization of Underground Facilities," on 2 December 1999 at the University of Massachusetts' Center for Atmospheric Research.

Mr. Rasmussen presented a talk on "HAARP Diagnostics" on 16 April at the RF Ionospheric Interactions Workshop in Santa Fe, NM.

HAARP Program Planning: Given the nature of Congressional Initiative Programs, out-year planning is a continuing challenge, as the government may not obligate or commit funds to undertake activities that require funding from more than a single year's appropriation. This requires tailoring of activities for contractual actions to be consistent with current-year Congressional appropriations and authorizations. In addition, out-year planning is updated to structure work consistent with expected Congressional funding levels. Mr. Rasmussen and Dr. Snyder participated in such planning with the HAARP management team, the prime contractor (APTI) and with individual diagnostics contractors to define realistic work packages and to update associated cost estimates.